Evaluating the change of consumption and culinary practices at the transition to agriculture: a multi-disciplinary approach from a Danish kitchen midden.

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Harry Kenneth Robson
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University of York
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Abstract

Due to the excellent conditions for preservation of anthropogenic materials, the introduction of domesticated fauna and flora into southern Scandinavia, ca. 3950 cal BC, has been debated for over 165 years. In order to test questions relating to the nature and timing of this cultural change, the Mesolithic-Neolithic transition, a number of archaeological and biomolecular techniques have been applied in recent decades. The carbon and nitrogen stable isotope analyses of human bone collagen is one such method that has been regularly performed. Interestingly, every study has argued for a dramatic or sudden dietary change (Tauber 1981) despite evidence to the contrary (Milner *et al*. 2004). However, there has not been a single study that has employed a range of techniques to materials derived from one site in order to evaluate the change of consumption and culinary practices across the Mesolithic-Neolithic transition.

This thesis uses a combination of stable isotope analyses (carbon, nitrogen and sulphur) and radiocarbon dating of human bone collagen to reconstruct long-term dietary practices, and place these individuals into context. In order to provide an indication as to when the site was occupied, incremental growth line analysis of the European oyster (*Ostrea edulis*) was undertaken. In addition, organic residue analysis of ceramic vessels was performed to explore food consumption as well as culinary practices. Furthermore, an archaeoichthyological analysis was carried out to reconstruct the subsistence economy. This marks the first large-scale application of these methods to materials derived from one kitchen midden. Furthermore, it includes materials derived from 32 additional contemporaneous sites. The combined results demonstrate a degree of complexity: some things changed, others remained the same and there was variation both between sites and regions.

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Author's declaration

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Incremental growth line analysis of oyster shell samples from Bjørnsholm, Dyngby I, Dyngby III, Eskelund, Eskilsø, Havnø, Krabbesholm II, Lystrup Enge, Norsminde, Vængesø III and Visborg was carried out by Professor Nicky Milner and Dr Eva Laurie, University of York. The analysis of oyster shell samples from Brovst, Ertebølle, Havnø, Holmegård, Kalvø and Tybrind Vig was collaboratively undertaken with Dr Eva Laurie and Professor Nicky Milner.

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The ichthyoarchaeological analysis was undertaken with some assistance from Dr Andrew Jones.

The research presented in this thesis, unless stated otherwise, has not been published or previously submitted for a degree at this university or any other institution by this author or any other. However, Appendix 1 provides a list of conference abstracts resulting from this thesis that were presented by the author. The 'American Psychological Association' (APA) style for in text citations and bibliographic formatting was used.

1. Evaluating the change of consumption and culinary practices at the transition to agriculture: a multi-disciplinary approach from a Danish kitchen midden

1.1. The necessity of the study

The consumption of resources of marine origin has been a source of nutrition for millennia. Consequently in numerous coastal regions across the globe, sites which compose their remains have emerged which can be studied intensively. One such region of study is southern Scandinavia, in particular Denmark where research on coastal sites has been undertaken for the last 187 years. The theory that resources of aquatic origin were heavily utilised during the Danish Mesolithic is well established, and is represented by extensive research on coastal localities some of which are at present submerged (Andersen 1995, 2013a; Fischer 1993, 1995, 1997, 2007; Milner 2012). However, it is the so-called Danish kitchen or shell middens or mounds that are the most renowned. They are a special type of site that are principally composed of the remains of millions of marine molluscs (Andersen 2000a, 2004a, 2007, 2008a).

The change from a hunting-gathering-fishing economy to one that practiced agriculture is considered to be one of the most important transitions in human history. This change has been debated for over 165 years in Denmark because of the excellent conditions for preservation of archaeological material from these periods (Fischer and Kristiansen 2002). The Danish kitchen middens in particular are one type of site that has received detailed examination. Whilst the majority, largest and most famous are dated to the late Mesolithic Ertebølle culture (ca. 5400-3950 cal BC), there are some stratified kitchen middens that also encapsulate the transition and accumulate into the early Neolithic Funnel Beaker culture (ca. 3950-2800 cal BC) such as Bjørnsholm, Havnø, Krabbesholm II, Norsminde, Vængesø III and Visborg (Andersen 1989, 1991, 2000b, 2005, 2008b; Enghoff 2011). Due to the very fine resolution of stratified material they offer the best opportunity for examining the degree of Neolithisation by the earliest agriculturalists and pastoralists of southern Scandinavia (Andersen 2000a, 2004a, 2007, 2008a).

In recent decades a number of scientific methods have been developed in order to test archaeological questions concerning the subsistence economy, seasonal exploitation practices, diet and food consumption and, more recently, culinary practices (Craig *et al*. 2011; Fischer *et al*. 2007; Laurie 2008; Milner 2002a; Saul *et al*. 2014; Tauber 1981). However, previous research has often focussed on one type of anthropogenic material or type of analysis. For instance, the carbon and nitrogen stable isotope analysis of human bone collagen from one site (Price *et al*. 2007), country (Tauber 1981) or region (Fischer *et al*. 2007) or evidence to suggest the continued processing of aquatic foodstuffs across the Mesolithic-Neolithic transition through the organic residue analysis of ceramic vessels (Craig *et al*. 2007, 2011).

This chapter firstly presents an overview of the Ertebølle culture and the proposed hypotheses for the transition to the Neolithic. This will be followed by a summary of the Funnel Beaker culture, and the debates that have centred on subsistence at the Mesolithic-Neolithic transition. At the end of the chapter the aim, research questions, and objectives as well as an overview of the thesis will be provided.

1.2. The Mesolithic of southern Scandinavia

1.2.1. Introduction

In southern Scandinavia, which is comprised of Denmark, Schleswig-Holstein in northern Germany and Scania in southern Sweden, archaeological research on the Mesolithic period (Middle Stone Age) commenced in the middle of the 19th century, and has continued until the present day (Fischer and Kristiansen 2002). In Denmark, Mesolithic research was not undertaken by chance but has, and continues to be focused and systematic (Sørensen 1996). Largely, this has been the result of the so-called ‘Three Age System’ that was originally proposed by C. J. Thompsen in 1836. His proposition was a subdivision of Danish prehistory into three ages, represented by stone, bronze and iron. However, it was not until 1927 when the term ‘Mesolithic’ was used to describe the period sandwiched between the Palaeolithic and the Neolithic of Denmark (Westerby 1927).

1.2.2. Landscape

The landscape of southern Scandinavia is characterised by undulating moraines and smaller islands, the three straits of the Lille Bælt, Store Bælt and Øresund, which connect the Baltic Sea with the Kattegat Sea, as well as numerous riverine and fjord systems. The North Sea demarcates the extent of southern Scandinavia to the west, whereas the Skagerrak to the north separates it from Norway (Blankholm 2008).

The beginning of the Postglacial, ca. 10,000 years ago is marked by an increase in temperature that steadily rose from a July mean of ca. 10 °C in the Late Glacial Younger Dryas to ca. 21 °C at the Boreal-Atlantic transition. Consequently, a forest succession took place in the region characterised by open birch (*Betula* sp.) and pine (*Pinus* sp.) forests in the Pre Boreal to pine and hazel (*Corylus* sp.) forests in the Boreal, and elm (*Ulmus* sp.), lime (*Tilia* sp.) and oak (*Quercus* sp.) forests in the Atlantic. As a result a change in the available fauna and flora also took place (Blankholm 1996, 2008).

At the peak of the glaciation, ca. 20,000-13,000 years ago, the sea level was ca. 90 m lower than the present. However, a gradual rise in the sea level to ca. 30 m below the present took place from the Late Glacial to the Boreal. The final increase in sea level rise took place within a very short period of time, ca. 600 years at the beginning of the Post Glacial. In the North Sea, the land bridge connecting the UK to continental Europe became submerged, whereas to the east, the freshwater Ancylus Lake became connected to the ocean. At some point during the Neolithic the Baltic Sea reached its current form (Blankholm 2008; Christensen 1993; Petersen 1985).

After the dramatic sea level rise, over the course of the Atlantic and Sub Boreal chronozones, the so-called Littorina transgressions occurred (Figure 1.1). They were represented by a series of sea level fluctuations that were between 0.5 and 2.0 m (Blankholm 2008; Christensen 1993). Contemporaneous isostasy also took place after the removal of ice in the region. Thus, a diagonal tilt-line running from the west coast of Jutland, south of the Limfjord to the island of Falster is present. North of this tilt-line, land has uplifted ca. 50-60 m above the present sea level, whereas to its south, which comprises

southern Jutland as well as some of the Baltic islands, the uplift has occurred at a much-reduced rate. Consequently the on-going sea level rise has inundated the former coastlines and archaeological sites (Blankholm 2008).

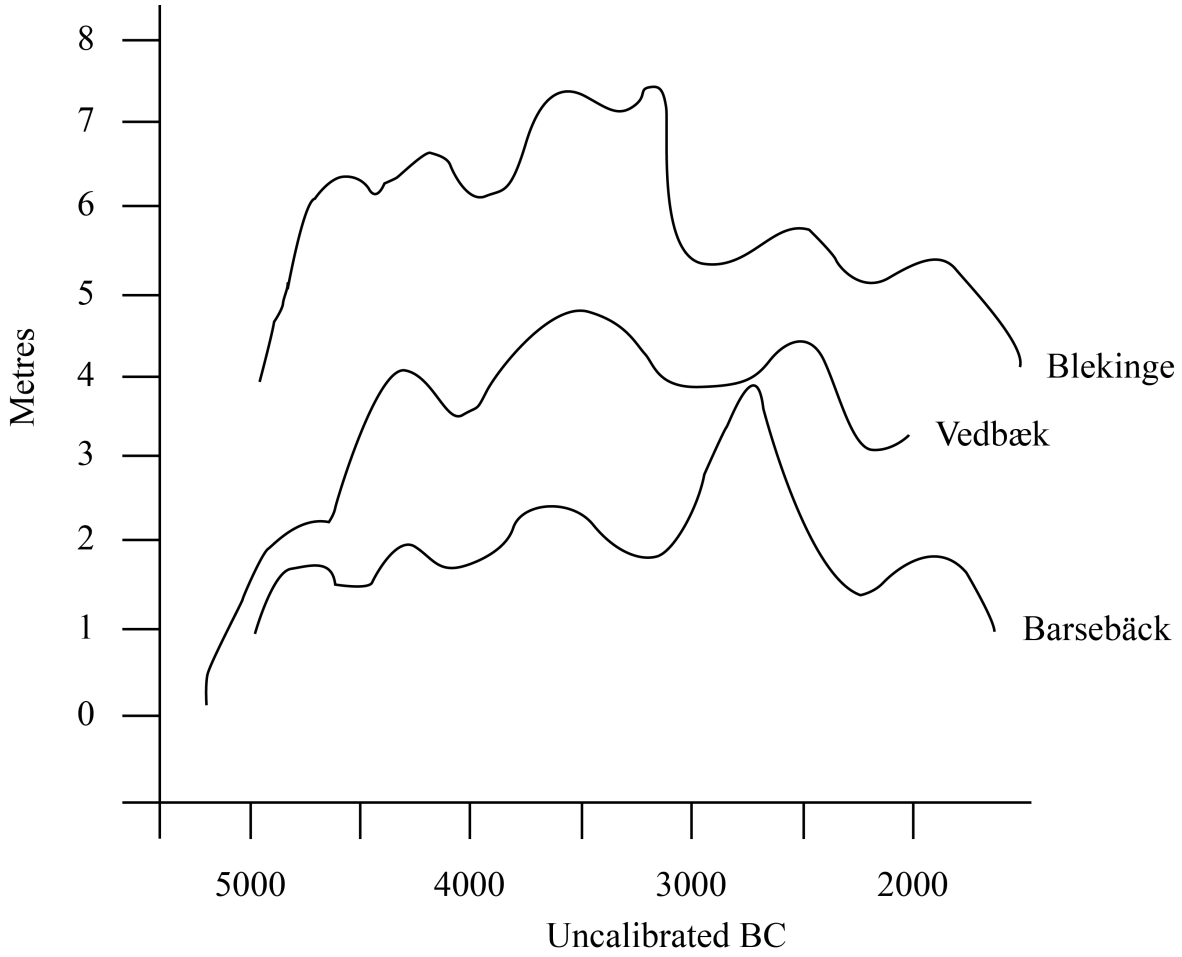


Figure 1.1: Sea level curves for the Littorina regressions and transgressions recorded at three Danish archaeological sites (redrawn and modified from Rowley-Conwy 1984, figure 9).

The cultural chronology for southern Scandinavia commenced with the Late Palaeolithic Hamburgian, Bromme and Ahrensburgian cultures, which were followed by the Mesolithic Maglemose, Kongemose and Ertebølle cultures. The material culture appears to have been continuous over the course of ca. 6000 years from ca. 9600-3950 cal BC. The beginning of the Mesolithic has traditionally been characterised by technology, the core axe, whereas the introduction of a new economy in the region, domesticated fauna and flora, characterises the onset of the Neolithic (Blankholm 2008).

1.2.3. The Ertebølle culture of southern Scandinavia

The terminal Mesolithic of southern Scandinavia is represented by the Ertebølle culture (hereafter EBK). Dating from ca. 5400-3950 cal BC (Rowley-Conwy 2004) it ended with the introduction of domesticated fauna and flora, and the start of the Neolithic (New Stone Age) with the Trichterbecherkultur/Tragtbægerkultur (Funnel Beaker) culture (Figure 1.2). The EBK is best described as a predominantly hunter-gatherer-fisher society that was distributed across Denmark, Schleswig-Holstein in northern Germany, Scania in southern Sweden and northern Poland (Figure 1.3).

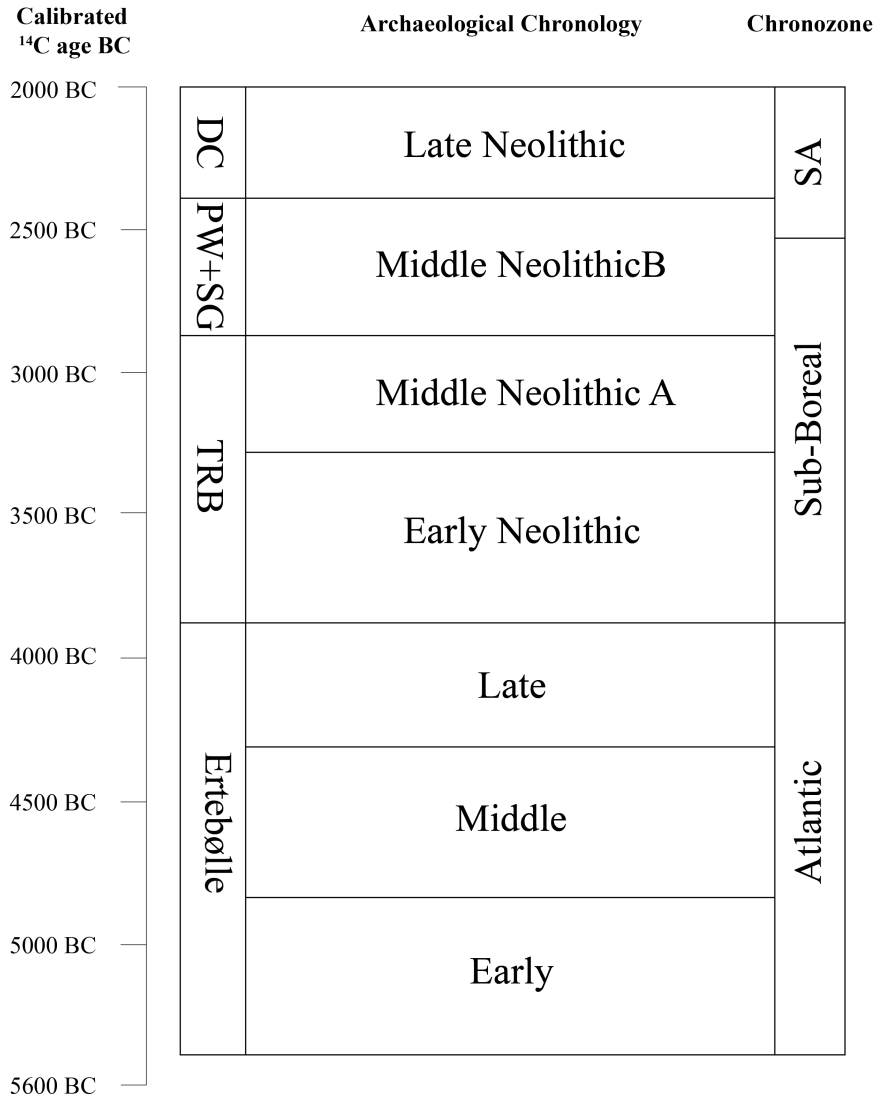


Figure 1.2: The chronology of the final Mesolithic and Neolithic of southern Scandinavia

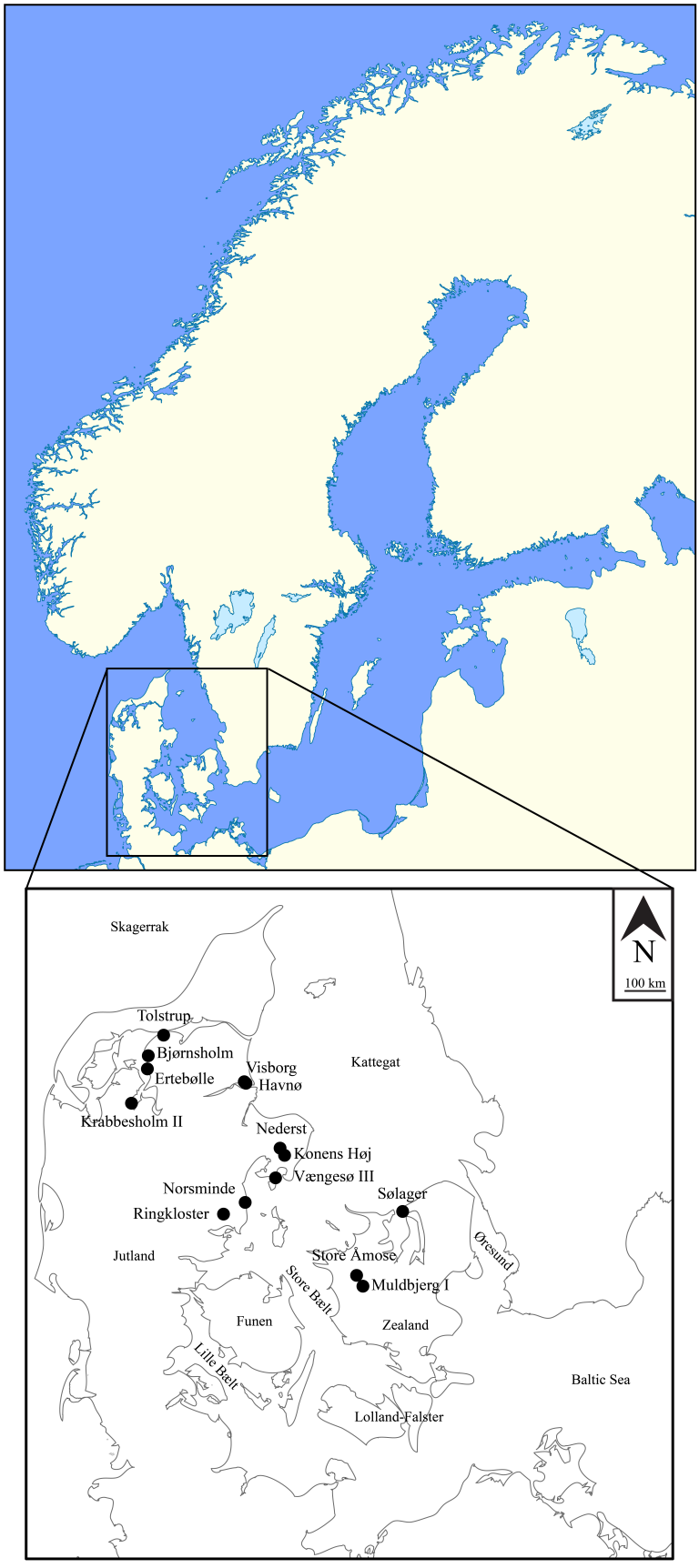


Figure 1.3: Maps showing southern Scandinavia (above) and the general region of the EBK culture as well as the sites mentioned in the chapter (below). Key: blue, water, cream, dry land.

The EBK is characterised by artefact manufacture, and is best represented by core and flake axes as well as transverse arrowheads. In addition, new forms of material culture, including ceramics represented by the pointed based vessels and the so-called blubber lamps, T-shaped antler axes, bone combs, rings and imported adzes are frequently encountered. Different forms of harpoons exemplify the importance of aquatic resource exploitation for the culture (Andersen 1995; Blankholm 2008). Buttons and pendants made from amber and teeth are usually recovered either as isolated finds or within inhumation burials, whereas a new form of material culture in the form of shell 'pearls' has recently been identified (Andersen 2008b; Blankholm 2008). There is a diverse array of wooden artefacts: arrows, bows, dugout canoes, fish traps, paddles, leisters, shafts, and weirs. Some of these were derived from managed forests (Blankholm 2008; Pedersen 1997, 2013).

It is during the EBK when regional trends are more pronounced when compared with the preceding Kongemose and Maglemose cultures. Regional differences have been identified in terms of the distributions of ceramics, bone combs and rings, flake axes, Limhamn greenstone axes as well as T-antler axes (Andersen 1980, 2010; Elliot 2015; Petersen 1984). However, this is probably attributed to site visibility, for instance the kitchen middens of the EBK as well as the numerous excavations that have been undertaken on contemporaneous archaeological sites.

In general, EBK peoples were capable of exploiting a broad range of natural resources from differing biotopes, including animals (Price and Gebauer 2005; Ritchie *et al*. 2013a), and plants (Kubiak-Martens 1999; Price and Gebauer 2005; Göransson 1988; Regnell *et al*. 1995). The species spectrum and relative abundance however is dependent upon a number of factors, including local biotope, season of occupation, type of site, not to mention differential rates of preservation and recovery (Blankholm 2008; Gron and Robson accepted). Although it would appear that there is an overemphasis on coastal localities, red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus)* and wild boar (*Sus scrofa*) are the most frequently identified terrestrial mammals. Elk (*Alces alces*) and auroch (*Bos primigenius*) are present though fewer by number (Blankholm 2008) which may in part be explained by population diminution particularly for the Danish islands of Funen and

Zealand (Gron 2013a). Fur bearing mammals, including badger (*Meles meles*), bear (*Ursus arctos*), beaver (*Castor fiber*), fox (*Vulpes vulpes*), lynx (*Lynx lynx*), pine marten (*Martes martes*), otter (*Lutra lutra*), wild cat (*Felis silvestris*), and wolf (*Canis lupus*) were probably exploited for their pelts, whereas the marine mammals are best represented by the common dolphin (*Delphinus delphis*), grey seal (*Halichoerus grypus*), harbour porpoise (*Phocoena phocoena*), harbour seal (*Phoca vitulina*), killer whale (*Orcinus orca*), and ringed seal (*Phoca hispida*) (Blankholm 2008; Enghoff 2011; Gron 2013a).

Fishing was not only a coastal activity but was also undertaken at inland localities. The most commonly identified species of fish from inland localities were pike (*Esox lucius*), perch (*Perca fluviatilis*), European eel (*Anguilla anguilla*), wels catfish (*Siluris glanis*), roach (*Rutilus rutilus*) and Salmonidae. The marine taxa are characterized by Gadidae, Pleuronectidae, spurdog (*Squalus acanthias*), mackerel (*Scomber scombrus*) and garfish (*Belone belone*). In addition, birds were probably fowled for their meat and feathers that could have been used as quills. There appears to have been little interest in forest dwelling species of bird, although waterfowl including ducks, swans and gulls are well represented (Blankholm 2008; Enghoff 2011; Gron 2013a; Madsen *et al*. 1900). Mollusc gathering was of major importance during the EBK particularly at coastal localities and is best represented by the European oyster (*Ostrea edulis*), common cockle (*Cerastoderma edule*), blue mussel (*Mytilus edulis*) and common periwinkle (*Littorina littorea*).

Since the majority of coastal localities are to be found north of the tilt-line, coastal settlement sites appear to be somewhat overrepresented (Blankholm 1987a, 2008; Newell 1984). Similarly, sites dominated by oyster shells are only recorded for areas that would have been saline enough to support the mollusc, generally in the north and northeast of southern Scandinavia (Blankholm 2008). Thus, there is a dearth of inland localities for the EBK (Andersen 1994-1995).

Taking the above into consideration, different settlement patterns have been suggested for the EBK. The most popular notion being that each band of peoples had their own fjord system as well as the adjacent islands or inland riverine systems and hinterlands

(Blankholm 2008). In addition, each band had their own centrally located base camp or site that was surrounded by a series of smaller sites, which were either established for a specific reason or for a particular time of the year (Andersen 1976a, 1981; Blankholm 1987a, 2008; Brinch Petersen *et al*. 1982; Petersen 1984).

Until the discovery of the coastal cemetery site at Bøgebakken the deposition of humans for the EBK was not very well understood (Albrethsen and Brinch Petersen 1976). Presently inhumation burials are known from ca. 50 localities in the region (Blankholm 2008). Since human remains are often recovered alongside other anthropogenic materials (Andersen 1994-1995), the distinction between cemeteries and settlements is somewhat obscured. Owing to the large sample size, health and physical status have been intensively explored. It has been estimated that the late Mesolithic and early Neolithic humans had a mean height of 154 and 166 cm for females and males respectively (Bennike 1985a, 1993). However, it has been observed that there was an increase in sexual dimorphism throughout the Neolithic (Meiklejohn *et al*. 1998). Health was generally good since there are only a few specimens with arthritis, caries, enamel hypoplasia, and porotic hyperostosis (Alexandersen 1993; Meiklejohn and Zvelebil 1991), which could indicate either a healthy population (Meiklejohn *et al*. 1998) or a reflection of the small sample size.

In addition, palaeopathological studies have demonstrated that females used their teeth for working hides, whereas males held material whilst it was being worked (Alexandersen 1993). Furthermore, *perimortem* evidence is represented by blows to the skull and embedded projectile points. These have been interpreted as violent interactions resulting in premature death, perhaps as a reaction to territory infringements or increased population pressure (Meiklejohn and Zvelebil 1991; Newell *et al*. 1979; Price 1985).

1.3. The transition to the Neolithic

Between the 1940s and 1970s two hypotheses dominated southern Scandinavia research regarding the transition to the Neolithic. The following two opposing ideas were posited: (1) the Funnel Beaker (hereafter TRB) peoples brought agriculture to the region as a developed package. However, due to a perceived superior form of production, the package

either expelled or absorbed the EBK peoples (Becker 1947; Brøndsted 1957), and (2) the EBK peoples learnt about agriculture from their Linearbandkeramik (hereafter LBK) neighbours to the south through the diffusion of ideas. They subsequently established a mixed economy that combined hunting, gathering and fishing with food production, and were invaded by the TRB peoples (Troels-Smith 1953).

Following the inception of the economic and processual archaeology of the 1970s numerous hypotheses have since been proposed (Andersen 1973, 1981; Blankholm 1987b; Fischer 2002; Jensen 1982; Paludan-Müller 1978; Rowley-Conwy 1981, 1983, 1984; Zvelebil and Rowley-Conwy 1984). In general they are based on 'a single, usually external, agent coupled with a triggering factor as the dominant cause of change' (Blankholm 2008, 126), for example, population or economic pressure or environmentally derived changes (Andersen 1989, 1991; Fischer 2002).

The most important issue has been the apparent delayed introduction of agriculture in southern Scandinavia. While the EBK peoples continued their way of life for over a thousand years, to the south LBK groups and sub-groups were well established. Despite this fact, it would appear that ideas and trade might have taken place between the two (Andersen 1973; Blankholm 1987b, 2008; Fischer 1993; Newell 1984; Rowley-Conwy 1983; Zvelebil and Rowley-Conwy 1984; Tilley 1996). A recent overview has demonstrated a considerable degree in favour of contact, perhaps with a symbolic value (Rowley-Conwy 2014). One artefact that has received considerable debate is the presence of the LBK and Rössen adzes in southern Scandinavia. Some authors have suggested that they reflect a desire for the exotic or prestige (Fischer 1982; Klassen 2002; Verhart 2012). Similarly, it has been suggested that the hunter-gatherer-fisher groups imported ceramics, lithic points, ornaments and females to the exchange of honey, pelts, and marine mammal fat (Alexander 1978; Fischer 2002; Klassen 2002; Vanmontfort 2008; Verhart 2012; Zvelebil 2006). Interestingly, this proposed trade demonstrated to Zvelebil (2006) that an increase in social competition is likely to have taken place that ultimately led to the destabilisation of the EBK. On the other hand, some have argued that the distribution of unique aspects of material culture did not represent a specialist trader, and merely a

reflection of the exchange of objects by hand (Terberger *et al*. 2009). Table 1.1 provides an overview of the direction of movement demonstrating a predominance of materials moving south.

Item	**Direction**
Projectile points	North→South
Stone adzes	South→North
Flake axes	North→South
Ceramics	North→South
Shell buttons	North↔South
Shell pendants	North↔South
T-axes	North→South
Decorated bone	North→South
Amber beads	North→South
Bows	North→South
Honey	North→South
Pelts	North→South
Marine mammal fat	North→South

Table 1.1: Items and assumed direction of transfer (after Rowley-Conwy 2014).

However, the archaeological record is biased. For instance there are only three inland EBK sites on Jutland that have been intensively excavated (Andersen 1994-1995). In addition, it is unclear as to how many LBK groups and sub-groups were in operation to the south (Barker 1985; Zvelebil *et al*. 1998). Thus, it is not clear if the EBK peoples resisted domesticated fauna and flora. Rather, they might have adapted unique elements of the Neolithic package, whilst pursuing a hunter-gatherer-fishing way of life (Blankholm 2008; Schulting 2011).

In addition, it has only recently been emphasised that some direct Accelerator Mass Spectrometry (hereafter AMS) radiocarbon dates may have been compromised by either freshwater or marine reservoir effects (Fischer and Heinemeier 2003; Meiklejohn *et al*. 1998; Persson 1999; Philippsen *et al*. 2010; Philippsen 2013; Philippsen and Meadows 2014). This has undoubtedly distorted the timing of the transition to the Neolithic. Despite this fact the earliest ceramics of the EBK are ca. 800 years earlier than the transition to the Neolithic. Conceivably this material culture may support the notion of a degree of contact

with groups outside of the immediate area (Andersen 2010, 2011a; Blankholm 2008).

While it is often assumed that the TRB peoples abandoned wild resources in favour of agriculture and domesticates, a hunter-gatherer-fisher way of life continued for some (Craig *et al*. 2011; Milner *et al*. 2004; Schulting 2011), whereas others are likely to have started using domesticated fauna and flora (Blankholm 2008). On some LBK sites EBK projectile points have been recovered. At the very least they imply a degree of contact between the two groups (Rowley-Conwy 2014; Weiner 1995), while some scholars have interpreted them as a continuation of the EBK across the transition (Robinson *et al*. 2010). In addition, stone axes appear to have been exchanged between the two groups. Although the EBK had their own stump-butted axe, LBK and Rössen adzes are frequently recovered throughout southern Scandinavia (Figure 1.4), generally as isolated finds (Fischer 1982; Verhart 2012). In comparison, EBK flake axes have been recovered from LBK localities (Rowley-Conwy 2014). Since there are no similarities between the ceramic vessels of the EBK and Swifterbant when compared to those of the LBK, it has been suggested that the transfer of knowledge and ceramics vessels are derived from the east (Jordan and Zvelebil 2009). Despite this, an EBK pointed based vessel has been recovered from the LBK site at Rosheim (Gronenborn 2009; Rowley-Conwy 2014). Furthermore, non-utilitarian items, for instance shell buttons and pendants have recently been recovered from Hornstaad-Hörnle on the Bodensee in southern Germany, Eggenburg-Zogelsdorfstraße and Hörsching-Haid on the Danube, as well as Rössen and Třebestovice near the Elbe (Heumüller 2009, 2012). Interestingly, identical specimens have been recovered from two kitchen middens in northeast central Jutland, Havnø (Andersen 2008b) and Nederst (Ritchie personal communication 2015). Although the species of shell has not yet been identified, the German specimens are assumed to have been manufactured from oyster (Heumüller 2009, 2012), whilst it is more than likely that the freshwater mussel (*Unio* sp.) was utilised (Demarchi personal communication 2015) for the Havnø specimens. From a cursory perspective, based in part on their similarity, oysters may have been exchanged in favour of freshwater mussels between the two groups.

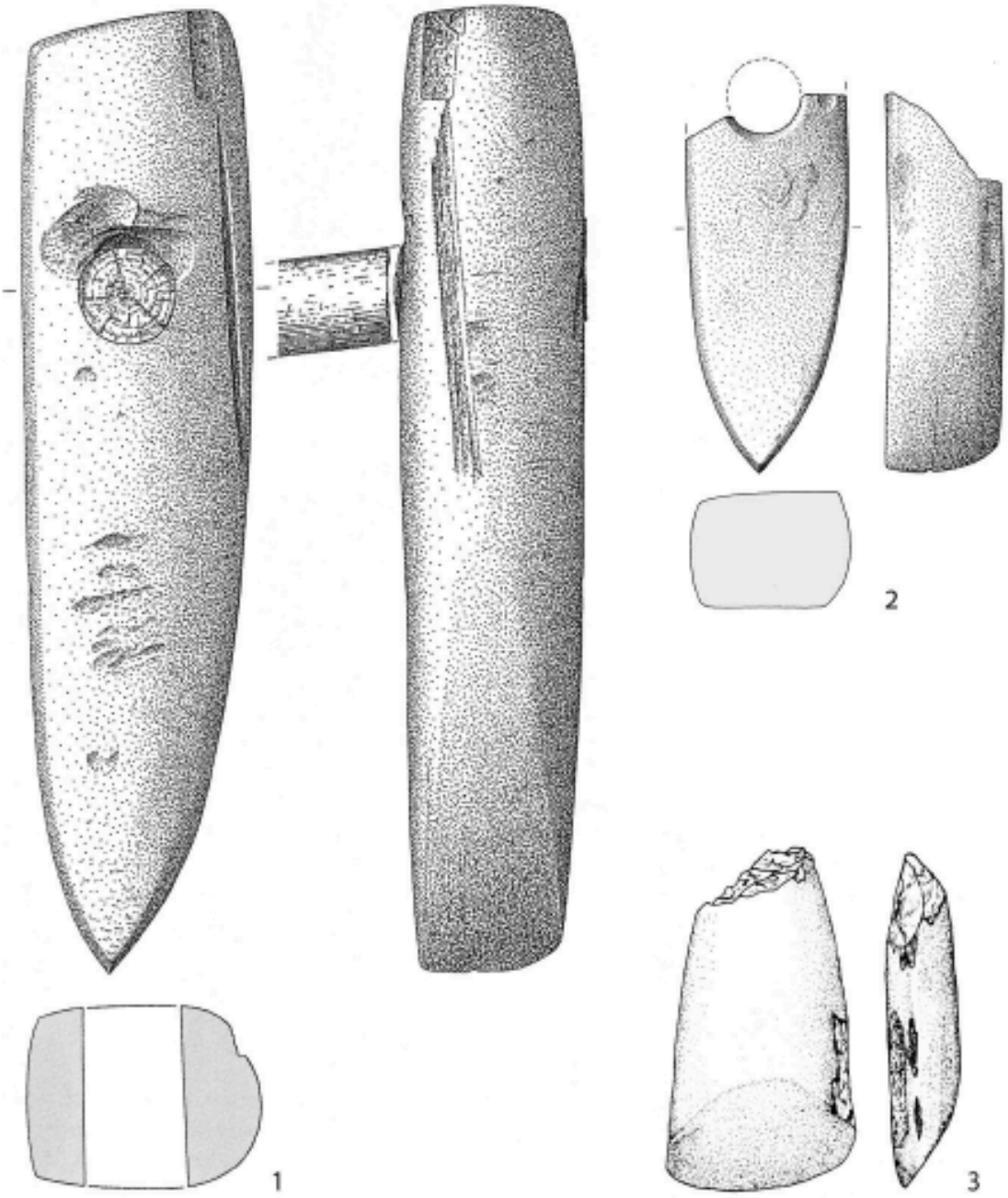


Figure 1.4: Imported stone axes of the Danubian type recovered from Rosenhof (1), Neustadt (2), and Lietze-Buddelin, northern Germany (after Hartz et al. 2007).

T-shaped antler axes were once thought to have been an EBK phenomenon (Andersen 2002), however it has recently been demonstrated that they had a wider geographical distribution. Typologically similar, they have been recovered from along the Baltic coast,

central Europe, the Iron Gates and southern Scandinavia (Elliot 2015). Based on a series of AMS radiocarbon dates it has been demonstrated that those from northern Germany predate the Danish examples, which have been interpreted by some as a part of the earliest Neolithic package (Crombé *et al*. 2002; Bogucki 2008; Gronenborn 2009; Hartz 2004; Kaute *et al*. 2004). Similarly, objects made of bone with geometric motifs and chisels have a wide geographical distribution, although their roots are firmly in the EBK, and not in the Neolithic (Bogucki 2008).

Some scholars have also argued that a change in the subsistence economy across the Mesolithic-Neolithic transition was one of the least important aspects (Andersen 1991; Tilley 1996). Initially domesticated fauna and flora may have been viewed as exotic items, perhaps with a prestigious or symbolic value that were integrated into the wider economy over the course of several decades from ca. 3950 cal BC (Blankholm 2008).

Over the last 40 years the presence of domesticates from EBK contexts has been the subject of considerable debate. In 1998 Zvelebil proposed that there were at least six possible domesticates dating to the EBK, however, in a more recent paper by Rowley-Conwy 'not one stands up to scrutiny' (2014, 197). It addition, it has been proposed that both domesticated cattle (Nobis 1975, 1978) and swine (Krause-Kyora *et al*. 2013) were present during the late Mesolithic at the waterlogged coastal site of Rosenhof, northern Germany. Although these species have been debated, for both, their wild congeners have been argued for (Noe-Nygaard *et al*. 2005; Rowley-Conwy 1985a, 1995; Rowley-Conwy and Zeder 2014a, 2014b; Scheu *et al*. 2008).

1.4. The early Neolithic of southern Scandinavia

The earliest Neolithic of southern Scandinavia is represented by the Trichterbecherkultur/Tragtbægerkultur/Funnel Beaker culture (TRB). Dating from ca. 3950-3300 cal BC, the culture is divided into two sub-cultures: the early Neolithic I (ENI, 3950-3500 cal BC), and the early Neolithic II (ENII, 3500-3300 cal BC). It is followed by the middle Neolithic (MN, ca. 2800-2400 cal BC) represented by the late TRB, Single Grave (hereafter SGC) and Pitted Ware (hereafter PWC) cultures, and the late Neolithic

(LN, ca. 2400-1800 cal BC) Dagger culture (hereafter DC) (Koch 1998; Price and Noe-Nygaard 2009).

Although the archaeological record for the early TRB (ENI) is substantially smaller than the preceding EBK it is characterised by marked differences in material culture and depositional practices (Andersen 2007; Johansen 2006; Koch 1998). While ceramic vessels had been present for ca. 800 years before the transition to the Neolithic (Andersen 2010, 2011a), it was during the TRB when regional types and styles of decoration became more frequent throughout southern Scandinavia (Koch 1998).

Wooden artefacts are plentiful and the heavy thin-butted or point-butted flint axe (polished or unpolished) is a characteristic of the culture and the Neolithic in general. In addition these axes have often been found in caches particularly in the later Neolithic and demonstrate a symbolic significance or use as a prestige item (Blankholm 2008; Koch 1998; Kristiansen 1984). They are also often recovered alongside their flint predecessors that are best represented by flake scrapers and sickle blades (Jensen 1982), as well as battle-axes, some of which were imported from elsewhere by exchange or trade. It is also during the TRB when the number of imported artefacts increased (Price 1996), for example the Danubian shaft-hole axe (Nielsen 1993).

In comparison with the EBK, the TRB is marked by a change in mortuary practices (Koch 1998; Price *et al*. 1995), including megalithic monuments that have been interpreted as an expression of power (Blankholm 2008) as well as non-megalithic types. However, megalithic architecture was not instantaneously incorporated and appears to have been introduced at the beginning of the ENII, ca. 3500 cal BC. It is represented by causewayed enclosures, earthen long-barrows, round barrows, long-dolmens and timber mortuary houses (Ebbesen 1992; Nielsen 1993; Liversage 1992). In general the timber mortuary houses are the most frequent and are distributed in western Denmark, notably Jutland. While they had no precursors they were sophisticated constructions ranging from raised chambers for example Konens Høj, to single entranced rectangular chambers for example Tolstrup (Madsen 1979, 1993).

In comparison with the EBK there was an increase in sexual dimorphism with males increasing and females decreasing. This appeared to have taken place from the early through to the middle Neolithic (Meiklejohn *et al*. 1998). However, it has been difficult to ascertain whether there was an increase in the number of infectious diseases due to the very small sample size. Whilst the instances of dental attrition appeared to decrease throughout the Neolithic, the levels of caries increased. In addition, the frequency of enamel hypoplasia was similar when compared to those from the preceding Mesolithic (Bennike 1985b, 1988; Meiklejohn *et al*. 1998).

On the whole the economy for the early TRB (ENI) is not very well understood when compared with the preceding EBK. This is based, in part, on smaller faunal assemblages (Andersen 2007; Johansen 2006; Koch 1998), as well as the coalescence of exploitation and settlement sites (Gron 2013a). Faunal assemblages from exploitation sites are best represented by the kitchen middens, some of which are stratified, for example Bjørnsholm, Norsminde, Sølager and Visborg, although inland localities have been identified, for example Muldbjerg I (Andersen 1989, 1991, 2007; Noe-Nygaard 1995; Skaarup 1973). These are broadly similar to their EBK counterparts and are predominantly composed of wild fauna and flora. Wildfowl, roe and red deer, wild boar as well as fur bearing mammals have been identified (Bratlund 1991; Skaarup 1973). However, fish remains are substantially fewer by number. When present, eel, flatfish and Atlantic cod (*Gadus morhua*) are best represented in the faunal assemblages from coastal localities (Enghoff 1989, 1991, 2011; Skaarup 1973). In comparison, faunal assemblages from settlement sites are either rare or small. When present, domesticated fauna including oxen (*Bos taurus*), pig (*Sus domesticus*), sheep/goat, and domesticated flora including einkorn wheat (*Triticum monococcum*), emmer wheat (*Triticum dicoccon*), and naked barley (*Hordeum vulgare*) dominate (Koch 1998; Møhl 1975; Nielsen 1985; Nielsen 1997).

It has been suggested that the economy for the TRB essentially represents a continuum from the EBK, particularly for coastal localities (Andersen 1989, 1991). While grain impressions have been identified in some TRB vessels (Jennbert 1984; Koch 1998; Saul 2011), the cultivation of cereals *stricto sensu* seems somewhat circumstantial (Blankholm

2008). Hunting, fishing and gathering appears to have been of primary concern for the early TRB (Blankholm 2008; Craig *et al*. 2011; Enghoff 2011). However, evidence to support a significant contribution of domesticated fauna and flora to the subsistence economy can be found at sites dating to the ENII (Jensen 1996; Price *et al*. 1995; Price and Noe-Nygaard 2009).

1.5. Change in subsistence at the Mesolithic Neolithic transition?

1.5.1. Introduction

For over 30 years there has been considerable debate surrounding the degree of change at the Mesolithic-Neolithic transition. This has been the result of advances in archaeological science, including the carbon and nitrogen stable isotope analysis of human bone collagen as well as the isotopic and molecular characteristics of lipids extracted from ceramic vessels. In this section a summary of the four main areas of debate that are directly related to the four research questions will be addressed.

1.5.2. Turning their backs on the sea

The seminal publication by Tauber (1981) is one of the most cited, and yet controversial studies indicative of a dietary change across the Mesolithic-Neolithic transition. The study, which included the carbon stable isotope analysis of human bone collagen, demonstrated that the Mesolithic humans' diet reflected the long-term consumption of marine derived protein, whereas the early Neolithic humans' diet was chiefly composed of terrestrial derived protein (Figure 1.5). Based, in part, on the AMS radiocarbon dates that were measured in conjunction with the stable isotope analysis, it was suggested that the dietary change was rapid (Tauber 1981).

Interestingly, regardless of location, every single study since undertaken on Danish archaeological material has argued for a dramatic or sudden dietary change (Clutton-Brock and Noe-Nygaard 1990; Fischer *et al*. 2007; Meiklejohn and Zvelebil 1991; Noe-Nygaard 1988; Persson 1999; Rasmussen *et al*. 2009; Richards and Koch 2001; Richards *et al*. 2003a; Tauber 1983, 1986). This is significant given the larger sample size (Figure 1.6), the

inclusion of $\delta^{15}N$ values that demonstrate the position of the consumer in the trophic level hierarchy, and additional AMS radiocarbon dates (Figure 1.7). Some scholars have even suggested that the Neolithic peoples 'turned their back on the sea', adopting agricultural products to the exclusion of aquatic resources (Richards *et al*. 2003b). While the marine-terrestrial change has been maintained, the only appreciable difference has been the correction of the AMS radiocarbon dates.

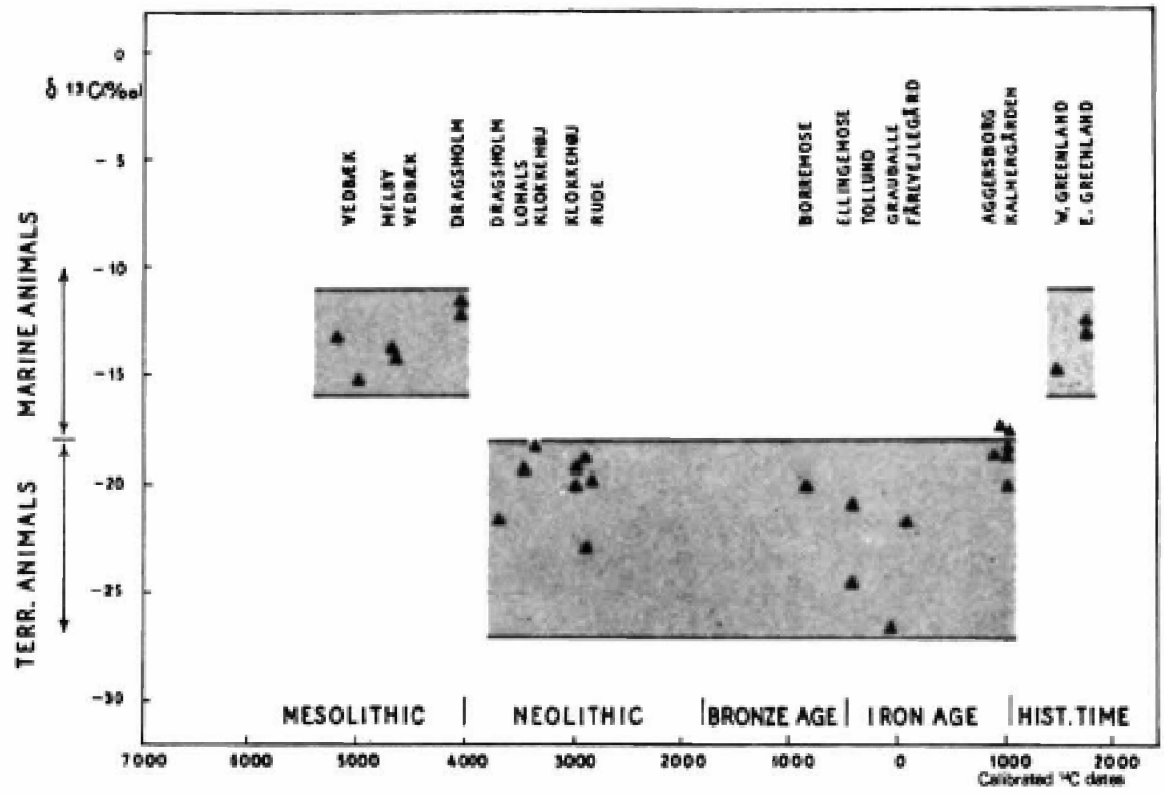


Figure 1.5: $\delta^{13}C$ data plotted against associative AMS radiocarbon dates (after Tauber 1981, figure 2).

On the whole, whilst these data demonstrated an unequivocal change they are still open to debate. Specifically in Denmark there is considerable evidence in support of marine fishing (Enghoff 2011; Pedersen 2013), mammal hunting (Enghoff 2011) and mollusc exploitation (Andersen 2000a, 2007, 2008a). In Denmark the kitchen middens accumulate well into the Neolithic and there are many younger kitchen middens dating to the Iron Age and Viking periods. Although it is clear that consumption practices changed, these localities provide unequivocal evidence that resources of marine origin still played their part to play in the

subsistence economy of the early Neolithic (Andersen 2000a, 2004a, 2007, 2008a).

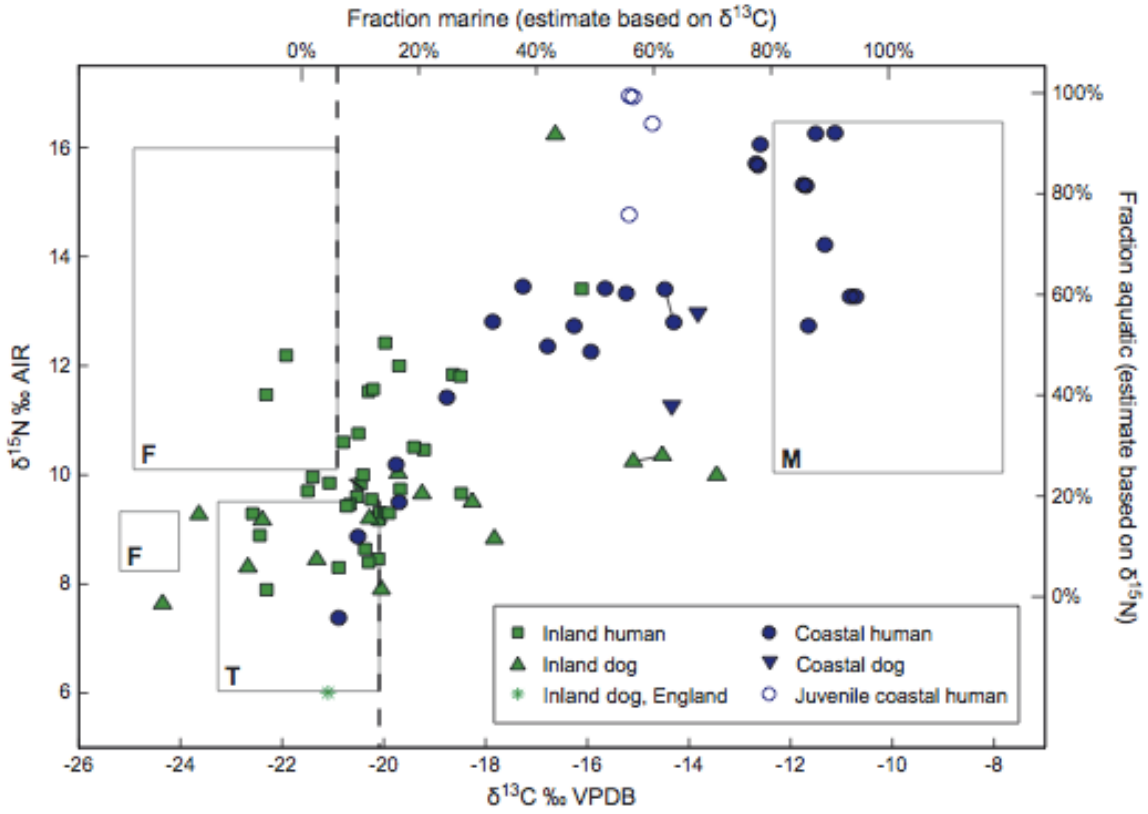


Figure 1.6: $\delta^{13}C$ and $\delta^{15}N$ data obtained from archaeological dog and human bone collagen dating from the early Mesolithic to the early Neolithic periods. The 'F', 'M' and 'T' boxes refer to the ranges established for freshwater, marine and terrestrial consumers respectively. The smaller and larger freshwater ranges refer to species of fish that were either lower down or higher up in the trophic level hierarchy (after Fischer et al. 2007, figure 4).

Moreover, it has been estimated that the sample set probably represents 0.000007% of the total population (Milner *et al*. 2004). Taking this into consideration, the current dataset is heavily reliant on EBK individuals recovered from coastal localities, whereas the majority of the TRB individuals are derived from inland sites (Fischer *et al*. 2007). Furthermore, these data are always plotted alongside one another to assess the degree of temporal change without taking into consideration intra-site and inter-site variability.

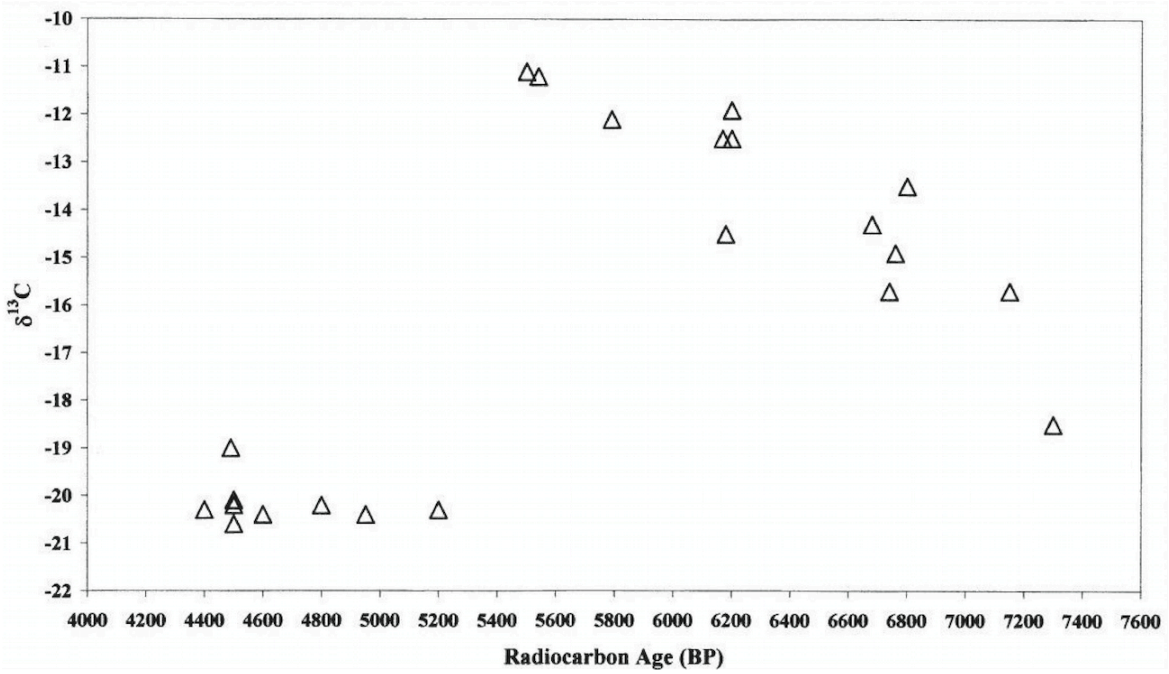


Figure 1.7: $\delta^{13}C$ data plotted against associative AMS radiocarbon dates (after Richards et al. 2003a, figure 2).

Overall there is a lack of appreciable data from one site, as well as human remains on either side of the transitional period, ca. 3950 cal BC. This has led to considerable debate regarding the application of carbon and nitrogen stable isotope analysis (Hedges 2004; Lidén *et al*. 2004; Milner *et al*. 2004, 2006; Richards and Schulting 2006).

More recently, a re-appraisal of these data has demonstrated that the character, extent, intensity and scale for a dietary shift remains unclear (Brinch Petersen and Meiklejohn 2009), and was probably not as instantaneous or synchronous throughout southern Scandinavia (Schulting 2010, 2011). Furthermore, it has only been recently demonstrated that the study by Tauber (1981) provoked more questioning. Notably, the AMS radiocarbon dates were not corrected for the marine reservoir effect (MRE) that can cause up to several centuries of uncertainty in measurement (Brinch Petersen and Meiklejohn 2009). This is based, in part, on the recycling of old calcium carbonates that are dissolved with the ground water. Consequently, if the measured $\delta^{13}C$ values of the EBK humans reflect a diet principally composed of marine derived protein, it is without a doubt that these values have been affected by the MRE (Chapter 3). Thus, the EBK peoples in some cases may be up to

400 years too old (Richards *et al*. 2003a).

1.5.3. Plugging the gap and the oyster decline

On the whole the oyster is the most prevalent marine mollusc deposited at the Danish kitchen middens. However, a change in the matrices has also been observed at several stratified kitchen middens (Andersen 1989, 1991, 2008b). In general the late Mesolithic layers are principally composed of the oyster and to a lesser degree cockle, mussel and periwinkle. In comparison it is the cockle that predominates the early Neolithic layers that are followed by the oyster, mussel and periwinkle.

While they are to be found in astonishing numbers their usage has been debated for some 40 years. Initially they were assumed to have been insignificant in terms of their calorific value despite being a source for certain vital minerals, for instance zinc (Bailey 1978; Clark 1975) or they were analysed in order to reconstruct exploitation territories (Bailey 1978; Jarman *et al*. 1982). In one of the most seminal publications on the topic by Rowley-Conwy (1984) their role was particularly challenged as they were considered as a part of the overall economy and ranking of species from the resource spectrum. In addition, it was argued that that they 'played an important role by filling a gap in the resource cycle in late winter and spring' (Rowley-Conwy 2002, 273; Figure 1.8). Furthermore, it was suggested that the introduction of domesticated fauna and flora at the beginning of the Neolithic appeared to coincide with a reduction in marine salinity that was the causal factor for their decline.

In general their relative importance as a major contribution to the overall diet of the populous has largely been ignored (Milner 2002a; Milner and Laurie 2009). Although it has been suggested that they were exploited specifically during the lean seasons of the year, this is the period in which they have the maximum calorific value and taste (Milner 2002b).

Interestingly, comprehensive research (Milner 2001a, 2002a, 2005, 2013) has largely been in agreement with Rowley-Conwy (1984), and has demonstrated that oysters were frequently harvested throughout the spring in the late Mesolithic. However, the analyses have also shown that regional variation concerning their exploitation was present, and that

there may not have been a significant shift across the Mesolithic-Neolithic transition for every site sampled (Milner 2013). Moreover, it is clear that oysters continued to be gathered during the Neolithic despite the preponderance of cockles, and they appear to have not become locally extinct (Milner 2013).

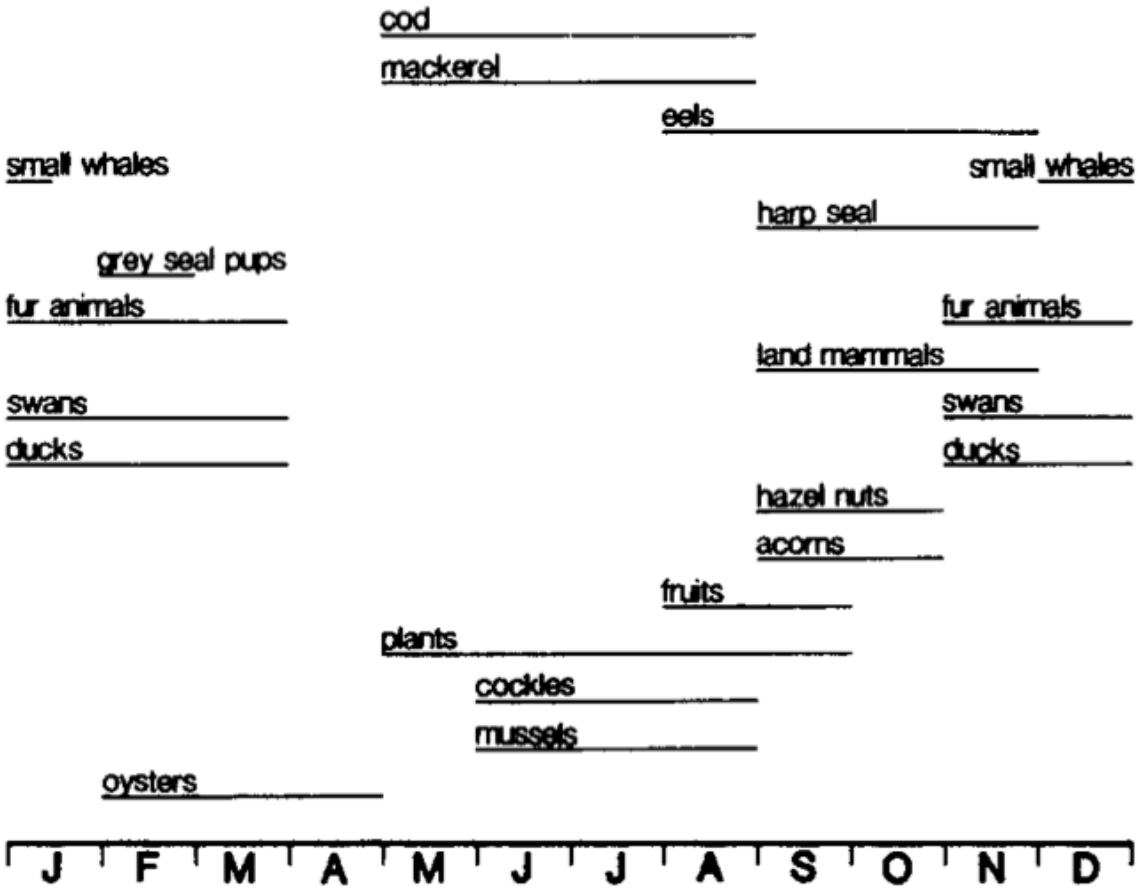


Figure 1.8: Predicted seasonality indicators for the western Ertebølle (Rowley-Conwy 1984, figure 3).

Rarely are the procurement strategies of shellfish considered. Although the four main species encountered, oyster, cockle, mussel and periwinkle tolerate similar salinities and sea temperatures they propagate in different biotopes, thus different exploitation methods are required. Since oysters are the dominant species of mollusc they are likely to have thrived in close proximity to the kitchen middens (Milner 2002a, 2009). However, location, tide and weather would have had an effect on how they were perceived and when they were harvested. Notably, neap and spring tides would have permitted easier access (Milner 2002a, 2005). Differences in their size have demonstrated that the gatherers probably

collected them at random. While collection tactics probably differed, in essence procurement would have at the very minimum involved a technique to dislodge them from their cemented locations. This activity could have been undertaken using a tool made from antler, bone, stone or wood (Milner 2002a, 2009). They were probably collected in baskets, clothing or nets although it is unlikely that they were transported considerable distances *en masse* given the considerable weight of live shellfish (Bailey 1978). Noteworthy are the 13 specimens that were recovered from the lakeshore settlement at Ringkloster, which is situated ca. 15-20 km from the coast (Andersen 1994-1995). It is unproven whether they were transported when live.

Despite the prevalence of oysters at the kitchen middens it is unclear whether they were primarily procured for direct consumption. However, recent experimental work by Søren H. Andersen and Esben Kannegaard has demonstrated that the oysters were probably placed on the embers of a fire or heated stones for a few minutes prior to consumption in order to extract the animal (http://videnskab.dk/miljo-naturvidenskab/sadan-spiser-du-osters-som-en-stenaldermand). The excavation of numerous hearths at a number of kitchen middens (Andersen 1989, 1991, 2000b, 2005, 2008b; Andersen and Johansen 1986) as well as the occasional recovery of oysters exhibiting exterior scorching supports this notion (Milner 2002a). Conceivably they could have been dried or smoked, perhaps stored in ceramic vessels or used as bait on fishhooks or within basket traps (Smart 2002).

Equally, while the oyster decline at the beginning of the Neolithic (ca. 3950 cal BC) is a well-known phenomenon in Denmark (Rowley-Conwy 1984), it has been difficult to ascertain the causal factors. In general, three hypotheses are posited: (1) environmental change, (2) human predation pressure, and (3) a combination of (1) and (2) (Milner 2002a; Milner and Laurie 2009). This is especially pertinent given the clear shift in oyster harvesting from the late Mesolithic to the early Neolithic (Milner 2002a, 2013).

1.5.4. Continuity in culinary practices

In 1984 Rowley-Conwy asked ‘it would be interesting to know what the Ertebølle pottery was used for’ (1984, 317). With the acceleration of biomolecular research since the 1980s it

is now possible to reconstruct what foods were prepared and cooked in the ceramic vessels of the EBK and TRB. On the whole, ceramics were once thought to be a central component of the Neolithic package, however, this assumption has been recently been discredited (Galili *et al*. 2002; Jordan and Zvelebil 2009). In addition, the application of AMS radiocarbon dating has also demonstrated that domesticated fauna and flora as well as ceramic technology had different trajectories (Dolukhanov *et al*. 2005).

In Denmark ceramic vessels appear approximately 800 years before the Neolithic, and are routinely recovered from EBK sites. Since they often contain food crusts (Chapter 5) including lipids that demonstrate the original use of the vessel, they can contribute to long-standing debates surrounding the origins of farming. Therefore, it is possible to assess whether wild resources were abandoned in favour of agricultural and pastoral resources because if this had taken place, the ceramic vessels may reflect this change. Furthermore it is possible to identify other uses of the vessels, for instance the presence of beeswax and dairy products that otherwise may have been overlooked (Craig *et al*. 2007, 2011; Heron and Craig 2011; Heron *et al*. 2007, 2013, 2015).

Ceramic vessels are interesting for several reasons. Firstly, they reflect a new type of container as a form of material culture. Secondly, they indicate a change in the preparation and consumption of foods that impact wider debates surrounding economy and subsistence. Whilst it is not known what caused this change from approximately the middle EBK, it has often been linked to the need for cooking and storage as well as the intensified use of herbs and vegetables (Andersen 2010, 2011a). In addition, it allows social, including personal identities and activities to be explored (Andersen 2010, 2011a; Saul *et al*. 2014). Lastly, the theme of cuisine from the analysis of ceramic sherds has recently been explored (Saul *et al*. 2012, 2013, 2014).

In southern Scandinavia and the southwestern part of the Baltic, ceramic technology appeared without any prototypes at the beginning of the middle phase of the EBK (ca. 4800-4300 cal BC). Since it had no local origin its initial appearance implied a degree of contact between regions(s) outside of this area (Andersen 2010, 2011a), and represented

either a cultural transition or technology transfer (Povlsen 2014). Nonetheless ceramic vessels entered the region as an end product of a well-developed technique that utilized carefully selected raw materials indicating an established morphological and technological pottery tradition before introduction (Andersen 2010, 2011a).

While some have argued that ceramic vessels represent the arrival of a Neolithic trait into the Mesolithic, others have argued that the emergence represented a precursor to the Neolithic package. Presently three different hypotheses exist.

The first is based on the general assumption that the EBK and Swifterbant ceramics of Belgium, the Netherlands and western Germany were influenced by the LBK and post-LBK groups to the south, which were combined with a local coiled basket tradition (Andersen 2010; Louwe Kooijmans 2010). This technology transfer reflects what has been termed an 'inspired reinvention instigated by contacts with farmers' (Povlsen 2014, 155) and is based on the adoption of a new form of material culture to fulfill the desire for the processing and consumption of new foods.

While some have argued that the pointed based vessels of the EBK and Swifterbant are similar in form and appear at roughly the same time (ca. 5000 cal BC) (De Roever 2004), others have stated that they are not related based on the number of differences between the other ceramics of the two cultures (Louwe Kooijmans 2010). For instance, the Swifterbant ceramics possess numerous stylistic differences including the lack of a flayed rim, a distinctive bend at the shoulder, thinner walls (ca. 1 cm thick), different temper (for example plant materials) and frequent decoration (De Roever 2004). In addition, there is an absence of oblong bowls/blubber lamps in Swifterbant assemblages, and the other material culture is considerably different (Andersen 2010).

The second hypothetical scenario is based on the unification of the ceramic traditions of the Boreal Neolithic and the Agro-pastoral Neolithic that met in northwestern Europe (Dumpe *et al*. 2011; Hallgren 2004). This is largely based on a thorough review of the Narva ceramics from two Latvian sites compared with the EBK (Dumpe *et al*. 2011). Despite the

presence of pointed based vessels and lamps in both the EBK and Narva cultures (Hallgren 2004; Timofev 1998) numerous differences exist, for instance temper (including shell and organic materials) and thinner walls resulting from the post construction modification with a comb like instrument. It has been argued that the shape and function of the EBK vessels were inspired by the east where the principles of construction were passed on from an established group (Dumpe *et al*. 2011).

The site 9 at Dąbki has received detailed consideration as a potential stepping-stone between the two regions along the east-west corridor (Povlsen 2014). Although this was based on the similarities between the Dąbki ceramics and those of the EBK, there are a number of differences, for example the construction technique of the pointed based vessels. Equally, differences exist between the Dąbki and Narva ceramics. Although a technology transfer has been suggested between Narva and the EBK (Dumpe *et al*. 2011), and Narva and Dąbki (Povlsen 2014), these interpretations should be treated with a degree of caution since only the one site is represented.

The third scenario is that the EBK ceramics had their primary roots in the eastern forager related ceramic traditions of the southeastern Baltic, and therefore they are more related to the Boreal Neolithic than the agro-pastoral Neolithic (Andersen 2011a; Davison *et al*. 2009; Dolukhanow *et al*. 2005; Dumpe *et al*. 2011; Gronenborn 2011; Hallgren 2004; Jordan and Zvelebil 2009; Klassen 2004; Timofev 1987, 1998; Van Berg and Cauwe 1998). The hypothesis is based on a degree of social contacts, impulses and influences on the technology as well as the economy that was dispersed by watercraft along the aquatic systems into the southwestern Baltic region (Andersen 2010; Povlsen 2014). In support of the above both the Neman and Narva cultures of the southeastern Baltic had a combination of pointed based vessels and lamps (Hallgren 2004). The ceramic vessels from these cultures have been dated to ca. 5100 cal BC (Hallgren 2004), and as such they are several centuries before the occurrence of pottery at the site 9 at Dąbki, Poland (Kabaciński and Terberger 2011) and northern Germany (Hartz and Lübke 2006), both ca. 4750 cal BC.

While their appearance was once thought to coincide with a change in the types of foods

consumed, the organic residue analysis of EBK and TRB ceramics has recently demonstrated that resources of freshwater and marine origin continued to be processed well after the introduction of faunal and floral domesticates (Craig *et al*. 2011; Saul *et al*. 2014; Heron *et al*. 2015). Thus, there is little evidence to support the notion that ceramics and domesticates are intrinsically linked (Craig *et al*. 2011).

1.5.5. Touch not the fish

In total, 294,839 fish remains deriving from 80 Danish archaeological sites have been identified (Enghoff 2011; Ritchie 2010). Based, in part, on these data it has been concluded that the fishery from the Kongemose to the Funnel Beaker cultures was both conservative and stable (Enghoff 2011). However, the situation is far from straightforward. Despite often-favourable conditions for preservation, it has been difficult to assess the degree of temporal change. Throughout the country numerous fish procurement implements dating to the TRB (Appendix 4) have been recovered (Andersen 1995; Pedersen 1997, 2013). While these data imply a substantial fishery, and one that could be considered more technically advanced when compared to the EBK, there is a general paucity of fish remains from TRB contexts (Chapter 6).

Initially their underrepresentation within both EBK and TRB faunal assemblages was probably attributable to the recovery methods employed during archaeological excavations. However, the general focus toward EBK archaeological sites as well as conditions conducive to preservation are the most probable reasons. Prior to the 1960s sieving was rarely employed, thus, numerous fish remains are likely to have been lost. However, since then fish remains have been frequently recovered, in particular from EBK contexts (Enghoff 1994, 1995, 2011; Ritchie 2010). In addition, while it would appear that sieving is routinely undertaken, variable mesh sizes throughout the country have had an effect on their frequency within faunal assemblages. For instance, the excavations that have been undertaken in the west of the country have, in general, used smaller mesh size when compared to those in the east. As a consequence there are more available assemblages from archaeological sites on the Jutland peninsula (Ritchie in print). In addition, the western part of the country has been the subject of comprehensive excavations, notably the kitchen

middens. For comparison, the majority of early Neolithic sites in the eastern part of the country are located in the Store Åmose in which the sieving of peat matrices is more challenging.

Despite the stratified kitchen middens that document the change from the Mesolithic to the Neolithic, there is, in general, a dearth of fish remains. For instance only one Gadidae bone was recovered from the TRB layers at the kitchen midden at Norsminde (Enghoff 1989). While Enghoff (1989) suggested that this was probably a reflection that fishing played a minor role during this period (Enghoff 2011), taphonomic factors were ignored *in toto*. On the whole TRB layers at a given site are located higher up in the sequence and therefore are more susceptible to post depositional alteration. In support of the above the faunal remains were generally highly fragmented in the Norsminde assemblage. It is possible that the low identifiability rate is probably due to colluvium since deposition (Gron personal communication 2015).

1.5.6. Transitional trajectories

Whilst these approaches have produced more data and further discussion concerning subsistence across the Mesolithic-Neolithic transition, more questions have been posed than definitively answered. One aspect that has become clear is that the data are more complex than originally perceived and that variation exists between sites and regions. Thus, this thesis provides a new perspective by comparing different approaches and data from one kitchen midden, which has not been previously undertaken in order to examine this complexity further. In addition, these data will then be put into the wider context, some of which is also the result of new study as a part of this thesis in order to examine the question of scale across the Mesolithic-Neolithic transition.

1.6. Aim

Since there has not been a single study that has encompassed a range of archaeological and biomolecular methods and techniques to provide a more holistic interpretation for one site, the aim of this thesis is:

To evaluate whether a change in diet, consumption practices and subsistence occurred across the Mesolithic-Neolithic transition at the Havnø kitchen midden.

1.7. Research questions

In order to examine this, the following research questions have been posed:

(1) Are marine resources still consumed in the early Neolithic, evidenced from carbon and nitrogen stable isotope analysis of human bone collagen?
(2) Is there evidence for a change in the seasonal exploitation of the European oyster across the Mesolithic-Neolithic transition?
(3) Is there a change in the preparation and culinary practices across the Mesolithic-Neolithic, evidenced from organic residue analysis of ceramic vessels?
(4) Do fish continue to be exploited in the early Neolithic?

1.8. Objectives

In order to address the research questions the following methods were used:

(1) A combination of Elemental Analysis-Isotope Ratio Mass Spectrometry (EA-IRMS) of human and faunal bone collagen as well as Accelerator Mass Spectrometry (AMS) radiocarbon dating to answer research question 1.
(2) Incremental growth line analysis of the European oyster to answer research question 2.
(3) The organic residue analysis of ceramic vessels by Elemental Analysis-Isotope Ratio Mass Spectrometry (EA-IRMS), Gas Chromatography (GC), Gas Chromatography-Mass Spectrometry (GC-MS), and Gas Chromatography-Combustion-Isotope Ratio Mass Spectrometry (GC-C-IRMS) to answer research question 3.
(4) Ichthyoarchaeology to answer research question 4.

Using a combination of the above archaeological and biomolecular methods and techniques, different perspectives that are directly related to the inhabitants of the kitchen midden can be examined. In general they have been routinely undertaken on Danish prehistoric material, however, collectively they have not been used in conjunction with one

another.

In order to evaluate the long-term diets of the humans interred at the kitchen midden carbon and nitrogen stable isotope analysis was undertaken. This is significant since the current dataset is heavily reliant on EBK individuals recovered from coastal localities, whereas the majority of the TRB individfuals are derived from inland sites. Moreover, there has not been a single study that has encompassed both EBK and TRB human remains derived from one Danish kitchen midden.

To gain an impression as to when the inhabitants harvested the European oyster and occupied the kitchen midden, incremental growth line analysis was undertaken. Since previous analyses have highlighted that regional variation in their exploitation was present it is necessary to expand the current dataset.

Organic residue analysis of ceramic sherds was applied in order to explore the preparation and culinary practices undertaken by the inhabitants at the kitchen midden. Despite the large corpus of data presently available in the literature, there has not been one study on materials dating from both the EBK and TRB cultures from the one Danish archaeological site.

Lastly, to reconstruct the subsistence strategies of the inhabitants at the site, the fish remains were analysed. The fish remains in particular are especially pertinent given the general paucity of their remains from contexts dating to the ENI in Denmark.

1.9. Overview of the thesis

Chapter 2 provides a comprehensive overview of kitchen midden research that will be followed by a synopsis of the Havnø kitchen midden as well as other sites sampled in this study. Chapter 3 presents the carbon, nitrogen and sulphur stable isotope analyses of human and faunal bone collagen and interprets the AMS radiocarbon dates. In addition, the Bayesian mixing model Food Reconstruction Using Isotopic Transferred Signals (FRUITS) will be applied to obtain a prediction of the consumers' diet. The incremental growth line

analysis of the European oyster is the subject of Chapter 4. This technique has proven useful for determining the season of collection as well as whether a diachronic change in the age and size of the shells took place. The organic residue analyses of the ceramic vessels are discussed in Chapter 5. In Chapter 6 the analysis of the fish remains are provided. Chapter 7 evaluates whether a change in diet consumption practices and subsistence took place at the Havnø. In addition, it will assess the applicability of the study. Furthermore, it will conclude the study and suggest future research opportunities that would be usefully applied.

2. Danish køkkenmøddinger

2.1. Introduction

Whilst there are many research studies for the southern Scandinavia Mesolithic, all of the sites sampled in this study were located in Denmark. The Havnø kitchen midden in particular was selected since the excavations at the locality had only recently been completed, and materials were available for analyses. However, in order to place the kitchen midden into the wider context it was decided to sample from contemporaneous sites within the immediate vicinity, for instance Thygeslund and Visborg, which are located in the same fjord. For comparison, similar sites situated in Jutland were intensively sampled and examined, as well as sites located within the different regions of Denmark, for instance Funen and Zealand.

Since the majority of the samples are derived from kitchen middens, these sites will be the primary focus of this chapter. Firstly, a history of research and an overview of the Danish kitchen middens will be provided. Background information including a synopsis of previous research undertaken at Havnø will follow. Lastly, the contemporaneous coastal and inland localities from which samples have been analysed throughout this study will then be presented.

2.2. Kitchen middens

2.2.1. Definition and distribution of the Danish køkkenmøddinger

Since peoples around the world have consumed marine molluscs for millennia, conflicting definitions of the term 'shell midden' exists (Milner 2002b). Variability in terms of content, form and size is present worldwide, for instance the shell middens of Portugal often contain numerous inhumation burials intermixed with fragmentary marine molluscs, which reach heights of 5 m (Gutiérrez-Zugasti *et al*. 2011). In comparison, the kitchen middens of the Danish Jutland peninsula tend to be elongated in form, and may stretch as far as 750 m along the former coastlines (Andersen 2000a; Blankholm 2008). Simply put, kitchen or shell middens are an anthropogenic accumulation of which the principal component is

marine mollusc (Waselkov 1987).

For the purposes of this thesis, a refined definition needs to be used since there are numerous definitions in the literature that have been used to describe the formation processes of individual shell accumulations: shell-bearing site, shell matrix site, shell midden, and shell-bearing midden site (Claassen 1998). Thus, the Danish kitchen middens of the EBK, TRB and later periods are defined as a special type of coastal settlement in which at least 50% of the volume consists of marine molluscs or their fragments, and which the area of the shell deposits forms a continuous horizon exceeding at least 10 m^2 (Andersen 2008a). If the deposit does not adhere to these criteria, but still contains shells, then the site is called a shell-bearing site or one with scattered shells or isolated shell heaps (Andersen 2000a, 2001, 2004a, 2008a).

In comparison with other countries along the Atlantic Façade, Denmark has the highest number of recognised kitchen middens. Presently only 480 preserved kitchen middens remains (Andersen 2007; Blankholm 2008). In addition, a number of natural mollusc banks dating to prehistory have been identified that have aided in our interpretation of the available species as well as those that were favoured by the inhabitants of the time (Gutiérrez-Zugasti *et al*. 2011).

2.2.2. History of research

The Danish prehistoric coastal settlements composed of thick layers of marine molluscs (køkkenmøddinger, kitchen middens or shell middens) are world famous, and research into these sites goes back to between the 1820s and 1830s. The kitchen midden at Krabbesholm I, located in the Limfjord in northern Jutland is the oldest registered site in Denmark (Andersen 2005). Between 1828 and 1831 it had been recognised as such, and by 1837 artefacts from the kitchen midden had been sent to the National Museum in Copenhagen (Andersen 2000a).

In 1848 *The Leijre Committee* was established. This multi disciplinary working group comprised an archaeologist, botanist, zoologist and expert on molluscs (Andersen 1989)

with the sole intention of ascertaining the nature of the so-called 'hævede havstokke' (literally translated as raised wave barriers, Trolle Jensen 2013, but also known as raised beaches). Since these barriers contained faunal materials, hearths with ceramics, lithics as well as substantial quantities of marine molluscs it was unclear whether or not the sites had been humanely created or represented natural phenomena. Originally the working group was called *The Leijre Committee* although it was subsequently renamed *The First Kitchen Midden Commission* (Figure 2.1). From 1850 to 1851 excavations were undertaken at the Havelse Mølle kitchen midden in northeast Zealand, and the large kitchen midden at Mejlgård in north central Jutland under the direction of J. J. A. Worsaae. The investigations yielded *in situ* layers of the three predominant species of shellfish, ceramic sherds that lay together, which could be refitted, as well as faunal remains that had been split and fractured in a consistent manner in order to extract the marrow (Rowley-Conwy 2013). The settlement remains demonstrated to Worsaae that these accumulations were a unique type of prehistoric site and not simply assumed natural shell banks containing artefacts. Thus, *The First Kitchen Midden Commission* concluded that these sites represented anthropogenic deposition, which reflected a past population that had been a social one, and one that been privy to feasting (Brinch Petersen 2011; Forchhammer *et al*. 1851).

However, debate surrounding these accumulations followed in the intervening years before the establishment of *The Second Kitchen Midden Commission*. This was largely between two prominent antiquarians: Japetus Steenstrup and J. J. A. Worsaae. While Forchhammer *et al.* (1851) considered them to be of a similar age to the megalithic tombs, Worsaae (1859) took a Darwinian evolutionary perspective. He thought that they were older given the crudeness of the lithic inventory in comparison with the megalithic monuments. Although they were often termed 'Kjökkenmöddinger' (Forchhammer *et al*. 1851), the on-going debate as well as a rivalry led to the establishment of *The Second Kitchen Midden Commission* (Andersen 1989, 2000a).

Prior to the establishment of *The Second Kitchen Midden Commission,* in 1888 A. P. Madsen resumed excavations at the Mejlgård kitchen midden. Since a vertical section that had been placed through the shell heap had yielded shellfish, it was concluded that such

sites were the result of individual meals because there was little anthropogenic material (Rowley-Conwy 2013).

Figure 2.1: Photograph of the 1869 visit to the Sølager kitchen midden by the international archaeological congress (taken from http://www.kulturarv.dk/1001fortaellinger/en_GB/soelager/main - accessed 14/06/2011).

In 1893 *The Second Kitchen Midden Commission* was established under the direction of Sophus Müller. From 1893 to 1897 a series of excavations were undertaken at one of the largest kitchen middens in Denmark, Ertebølle, which is located in the Limfjord, northern Jutland (Figure 2.2). There were two intentions for the Ertebølle excavations: (1) to recover a large assemblage from one locality, and (2) to date the kitchen middens in relation to the megalithic monuments of the Neolithic and the forest succession (Gutiérrez-Zugasti *et al*. 2011). The resulting monograph, *Affaldsdynger fra Stenalderen undersøgte for Nationalmuseet* (Madsen *et al*. 1900) that appeared to close the aforementioned debate has been considered as one of the most prominent publications on Danish prehistoric research (Fischer and Kristiansen 2002). However, the volume was not only restricted to the

Ertebølle kitchen midden but also synthesised a number of other Mesolithic kitchen middens (Åmølle, Fårevejle, Havnø and Klintesø). While the analysis demonstrated to the authors that many of the kitchen middens belonged to the Mesolithic (Figure 2.3), Neolithic kitchen middens (Figures 2.4 and 2.5) were also recognised (Ålborg, Leire Å and Ørum Å) (Madsen *et al*. 1900). Following these initial excavations at the Ertebølle kitchen midden, the site became to the *Locus classicus* for the culture in 1919 (Andersen and Johansen 1986).

Figure 2.2: Photograph of the excavations at the Ertebølle kitchen midden during 1893-1897 (taken from http://www.dandebat.dk/dk-images/200p.jpg).

Although the focus of research had shifted from kitchen middens to peat bog sites, between the 1930s and 1940s *The Third Kitchen Midden Commission* was formed. Similarly a number of excavations were undertaken, particularly on the Djursland peninsula. The publication of the Dyrholm kitchen midden is perhaps the most important product of these campaigns (Mathiassen *et al*. 1942).

Despite a hiatus in prehistoric research, Danish kitchen midden research was resumed in the 1970s and 1980s under the auspices of Søren H. Andersen and Erik Johansen. Owing to the long tradition of inter-disciplinary research, these investigations involving both archaeologists and natural scientists were undertaken with the sole intention of determining the ecological and economic aspects of the Danish kitchen middens (Gutiérrez-Zugasti *et al*. 2011). Since the 1970s excavations have been undertaken at some of the classic kitchen middens, including Bjørnsholm, Ertebølle and Havnø, while previously untouched kitchen middens have also been investigated, for example Norsminde. A series of preliminary works have been published (Andersen 1989, 1991, 2000b, 2004b, 2005, 2008b; Andersen and Johansen 1986), which have been acknowledged by some as the work of *The Fourth Kitchen Midden Commission* (Kristiansen 2002).

Figure 2.3: Photograph of The Second Kitchen Midden Commission surrounding an inhumation burial at the Åmølle kitchen midden (after Kristiansen 2002, figure 2.4).

Figures 2.4 (left) and 2.5 (below): 'Shellmiddens next to Ørum Å', and 'Shellmidden at Fannerup'. Watercolours by A. P. Madsen, 1891 (National Museum of Denmark cited in Brinch Petersen and Meiklejohn 2007, 183).

2.2.3. Chronology

Brovst and Lystrup Enge represent some of the oldest kitchen middens in Denmark, and have been dated to ca. 5700-5600 cal BC. However, the majority, largest and most famous belong to the EBK (ca. 5400-3950 cal BC). In addition, some continue into the early TRB (ca. 3950-3600 cal BC) such as the Bjørnsholm, Havnø, Krabbesholm II and Norsminde kitchen middens with TRB layers overlying the EBK layers (Andersen 1989, 1991, 2005, 2008b). The direct AMS radiocarbon dates obtained from a number of the Danish kitchen middens demonstrate a surprisingly stable biotope, and one that was exploited for a considerable period of time, sometimes in the region of ca. 1000-1200 radiocarbon years (Gutiérrez-Zugasti *et al*. 2011). For instance, the Bjørnsholm kitchen midden has been dated from ca. 4700-4000 cal BC and then from ca. 4000-3500 cal BC (Andersen 1991).

2.2.4. Composition

The Danish kitchen middens similarly vary in terms of their cubic content, from ca. 10 to 5000 m^3. However, regardless of culture they are characterised by a narrow taxonomic

range of marine molluscs compared with a natural population. The four most important species identified include the European oyster, common cockle, blue mussel, and common periwinkle, which are normally larger and represented by older individuals.

Differences between the EBK and TRB layers have also been identified. In general the EBK layers are primarily composed of the European oyster and to a lesser degree the common cockle, blue mussel and common periwinkle. Remains of birds (ca. 44 species), fish (ca. 48 species), marine and terrestrial mammals (ca. 26 species), and humans, often disarticulated and scattered represent the faunal assemblage. In comparison with other European shell middens, dog and human burials are limited to a handful of Danish kitchen middens: Åmølle, Bjørnsholm, Brovst, Dragsholm, Ertebølle, Fannerup, Holbaeks Landssogn, Holmegård, Jaegerspris Aalborg, Kassemose, Nederst, Sejrø, and Vængesø II (Andersen 1970; Andersen and Johansen 1990; Boas and Rasmussen 1988; Kannegaard 2013; Madsen *et al*. 1900; Newell *et al*. 1979; Price *et al*. 2007). The anthropogenic material often includes bone artefacts, ceramics, charcoal, lithics and potboilers, whereas the settlement structures comprise of at least two types of hearths, pits as well as foundation cuts or stake hole arrangements, or indeed a combination of the two (Rowley-Conwy 2013).

In comparison, the common cockle followed by the European oyster, blue mussel and common periwinkle tend to dominate the TRB layers. While it has been demonstrated that the European oysters are significantly smaller in the succeeding culture (Milner 2002a), a similar spectra of faunal remains have been identified to the inclusion of domesticated fauna.

Marine molluscs and their fragments normally constitute between ca. 70-80% of the cubic content of the Danish kitchen middens, although the principal function of the shellfish has been difficult to ascertain. While they may have been primarily used as a subsistence resource, they may also have been used as fish bait (Andersen 2008a).

2.2.5. Settlement patterns and resource scheduling

In Denmark, kitchen middens are generally located in the north/north-eastern part of the country, which may in part be explained by the favourable conditions of the Atlantic, Kattegat and Skagerrak Seas during the Atlantic chronozone (ca. 6000-4000 cal BC). Furthermore the sea temperature was ca. 2-4°C warmer, more saline, richer in nutrients, which perhaps may have had a higher tidal amplitude (Andersen 2007; Burman and Schmitz 2005). As a prerequisite the EBK kitchen middens are always found on, or along the prehistoric coastlines. Sometimes they are close to natural mollusc banks that were intensively exploited, and at favourable fishing locations. Preferable localities include estuaries, fjords, islets, lagoons and sheltered bays (Fischer 1993, 1995).

The zooarchaeological evidence has demonstrated that the larger kitchen middens were probably occupied throughout the course of the year (Madsen *et al*. 1900), whereas the smaller sites (not necessarily kitchen middens) were potentially more selective in terms of the resources exploited, for example Agernæs (Richter and Noe-Nygaard 2003), and Ronæs Skov (Andersen 2009).

2.3. The Havnø køkkenmødding

2.3.1. Introduction

The Havnø kitchen midden is presently situated ca. 150 m away from the northern shoreline of the Mariager Fjord on the eastern coast of north central Jutland. At the time of material deposition it would have been located on the southern coastline of an isolated island (ca. 800-900 m long, ca. 200-300 wide) into the mouth of the fjord (Figure 2.6) that would have required a dugout canoe to access. The nearest mainland was < 2 km to the northwest, essentially where the large Visborg kitchen midden is to be found. During this period a substantial area of inter-tidal flats and shallow waters would have surrounded the island to the north, east and west. The deeper waters of the fjord, and the opening into the saline Kattegat Sea bordered the south of the island. However, since prehistory the fjord has narrowed due to the continued isostasy in the region, consequently there is extensive reclaimed land surrounding the former island (Andersen 2008b; Milner 2002a).

Figure 2.6: Map of the Mariager Fjord showing the location of the Havnø kitchen midden in relation to the kitchen middens at Åmølle, Thygeslund and Visborg. Key: cream, dry land throughout prehistory, grey, Littorina Sea, blue, present day sea (redrawn and modified from Andersen 2008b, figure 1).

It was initially excavated by *The Second Kitchen Midden Commission* in 1894, and has been re-excavated under the direction of Søren H. Andersen in 1995, and then from 2005-2013. Although Havnø is one of the so-called stratified kitchen middens dating from the EBK to the TRB, a series of direct AMS radiocarbon dates (n = 25) indicated that the site was in use from ca. 4540-1800 cal BC (Chapter 3).

In the following section a brief synopsis of the previous excavations and the resulting analyses will be provided. This will be listed in chronological order commencing with the excavations undertaken by *The Second Kitchen Midden Commission* to the re-excavations carried out in 1995, and from 2005-2013.

2.3.2. The initial excavations in 1894

In 1893 A. P. Madsen located and surveyed the kitchen midden at Havnø. At the site an intact shell layer was observed that spread over a distance of ca. 100 m. Where the layer was thickest a 23 m long by 2 m wide trench was placed through the kitchen midden in

1894. In addition, a 4 m long by 1 m wide trench to the west as well as a 15 m long by 1 m wide trench to the east of the larger trench were excavated (Madsen *et al*. 1900). Since there was no apparent stratigraphy the matrices were excavated in artificial levels of 20 cm (Newell *et al*. 1979). Overall 67 m^2 were investigated by *The Second Kitchen Midden Commission* (Madsen *et al*. 1900). The stratigraphy was recorded (Figure 2.7), and a number of photographs were also taken (Figure 2.8). They found two hearths as well as material culture including antler and bone tools, ceramics, and lithics (Andersen 2008b; Bay-Petersen 1978; Enghoff 2011; Fischer and Kristiansen 2002; Madsen *et al*. 1900). In addition, faunal remains, which were represented by 15 species of birds and 13 species of mammals, were recovered (Table 2.1). Unfortunately the data was inconsistently reported, and is generally restricted to the presence or absence of the specific species. Rarely are individual specimens quantified (Gron 2013a; Madsen *et al*. 1900). Furthermore, cranial fragments derived from one child as well as postcranial elements derived from probably two adults were identified (Madsen *et al*. 1900; Newell *et al*. 1979). Analysis of the charcoal recovered from the site demonstrated that the area was less wooden compared to the other kitchen middens investigated although oak, birch, elm, alder (*Alnus* sp.), willow (*Salix* sp.) and conifer (Pinopsida) were present (Andersen 2008b; Fischer and Kristiansen 2002; Madsen *et al*. 1900).

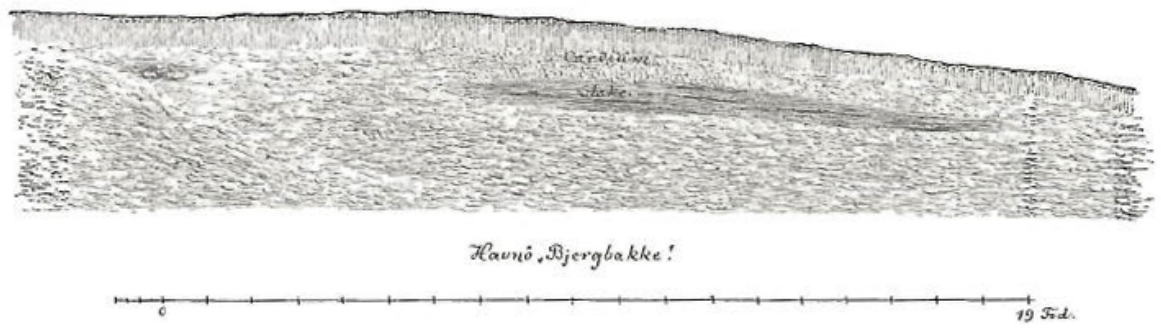


Figure 2.7: Section drawing by A. P. Madsen from the 1894 excavation at the Havnø kitchen midden. The description and signatures associated demonstrated that the upper part of the midden sequence composed of ash deposits and cockles, whereas the bottom layer was composed of oysters (after Andersen 2004b).

Figure 2.8: Photograph of the Havnø excavations in July 1894. From left to right: Madsen, Sarauw, Müller, unknown, Winge, unknown (courtesy of Søren H. Andersen).

Relatively recently the bird component of the faunal assemblage recovered by *The Second Kitchen Midden Commission* was re-analysed by Liv Ljungar (1996). During her analysis forest dwelling species of bird were absent that was in agreement with the observations made by Winge (Madsen *et al*. 1900). Noteworthy identifications included the Dalmatian pelican (*Pelecanus crispus*) and the great auk (*Pinguinus impennis*) (Ljungar 1996). These data are listed in Table 2.1.

2.3.3. Havnø re-visited in 1995

In 1995 a test pit was excavated at the Havnø kitchen midden under the direction of Søren H. Andersen. The recovered faunal remains have been analysed (Andreassen in Enghoff 2011; Enghoff 2011), and a pilot study on a sub-sample of oysters has been undertaken (Milner 2002a). The faunal assemblage encompassed both wild, including fur bearing and terrestrial mammals, as well as domesticates that indicated EBK and TRB occupation at the

kitchen midden (Andreassen in Enghoff 2011). The fish remains were derived from sediment samples and were dominated by the European eel. Numerous small Atlantic herring (*Clupea harengus*) remains as well as the dermal denticles from the European flounder (*Platichthys flesus*) were additionally identified (Table 2.1, Enghoff 2011).

Birds		**Mammals**	
Species	**NISP**	**Species**	**NISP**
Red-throated loon	4	Water vole	X
Red-throated/black-throated loon	1	Mouse sp.	X
Grebe sp.	2	Dog	7
Dalmatian pelican	1	Fox	5
Cormorant	2	Pine marten	3
Tundra swan	3	Swine	6
Whooper swan	5	Red deer	2
Swan sp.	58	Roe deer	2
Goose sp.	3	Ox	4
Mallard	X	Sheep/goat	2
Garganey	X	Horse	X
Eider	1	Grey seal	10
Black scoter	11	**Total**	**>41**
Velvet scoter	15	**Fish**	
Smew	X	European eel	>5
Red-breasted merganser	1	Flatfish	>2
Diving duck sp.	67	Herring	X
Gull sp.	2	Flounder	X
Great auk	3	**Total**	**>7**
Crow/rook	1	**Crustacean**	
Total	**>180**	Shore crab	X

Table 2.1: Relative abundance data (Andreassen in Enghoff 2011; Enghoff 2011; Ljungar 1996; Madsen et al. 1900). Key: X denotes presence.

In 1997 a pilot study was undertaken on 18 oyster shells in order to examine the season of gathering and the intensity of exploitation (Milner 2002a). The samples appear to have been extracted from an EBK layer deriving from a test pit (Andersen 2008b). Despite the small sample size the analysis demonstrated to the author that spring was the modal season although there was a discreet spread of collection events that took place from February to April. Summarising the results, Milner (2002a) stated that the sample most probably represented a single depositional episode that should not be used for assessing seasonality at the kitchen midden as a whole (Andersen 2008b; Milner 2002a).

2.3.4. The re-excavations from 2005-2013

Although the kitchen midden is awaiting full publication, a preliminary report on the first three years of the excavations from 2005-2008 has been published (Andersen 2008b). In the following section a summary of the key points from this publication will be provided. This will be combined with the subsequent analysis on some of the components of the faunal assemblages (Gron 2013a; Hellewell 2012a, 2012b; Milner 2013; Ritchie 2010; Robson 2010, 2011; Robson *et al*. 2009, 2013).

From 2005 to 2013 excavations under the direction of Søren H. Andersen were carried out at the Havnø kitchen midden. Initially the 1894 trench was re-located, and then a trench orientated north south was placed through the kitchen midden to examine the stratigraphy (Figure 2.9). Subsequently a series of larger squares, and slit trenches to the east and west of this trench were excavated. In addition, an area north of what has been termed the midden proper was opened up to determine: (1) the extent of the kitchen midden, and (2) to locate any evidence for dwelling structures. Furthermore, in 2013 an area beyond the larger squares to the rear of the midden proper was excavated. This resulted in the discovery of a secondary kitchen midden at the locality. In total, 171 m^2 were excavated (Andersen 2008b, personal communication 2009-2015).

In comparison with other Danish kitchen middens, the southerly kitchen midden, which is the primary focus of this study, is similarly oblong in form. It is estimated that this kitchen midden measures ca. 100 m in length by ca. 25-27 m in width. It is considered the largest coastal locality with the thickest shell deposits, ca. 70-90 cm thick, compared with ca. 15 sites in the immediate area (Andersen 2008b; Enghoff 2011; Madsen *et al*. 1900). Presently it is not possible to estimate the extent and form of the northerly, and thus secondary kitchen midden at Havnø.

In general three distinctive cultural layers in the midden sequence have been identified: the oldest dating to the EBK, the middle straddling the EBK-TRB transition and the youngest dating to the TRB. The three layers are stratified above a morainic subsoil of Late Glacial sandy clay (Andersen 2008b). The principle investigator has estimated that ca. 60-75% of

the kitchen midden material is dated to the Neolithic (Andersen personal communication 2013).

Figure 2.9: Photograph of the cross section through the Havnø midden during the August excavation campaign of 2011. Note that during prehistory Havnø was situated on what was once an island.

The kitchen midden appeared to have accumulated consistently horizontally and vertically throughout the course of material deposition. From the EBK to the TRB there is no evidence of a substantial occupation hiatus although the materials dating to the SGC and PWC most probably represent episodic and isolated single depositional events (Chapter 3). Overall, Havnø appeared to have been formed by the amalgamation of a series of smaller individual shell heaps, each measuring ca. 3-4 m in diameter, and ca. 10-20 cm in thickness. It has not been impossible to estimate how many are represented given the size of the kitchen midden but they probably number into the hundreds (Andersen 2008b).

Throughout the kitchen midden sequence the European oyster, which is an intertidal bivalve, is the dominant marine mollusc, and is followed by the common cockle in terms of

relative abundance. There are usually significant numbers of blue mussels and common periwinkles. Present though in lower frequencies include the carpet shell (*Tapes decussates*) and whelk (*Hinia decussata*). In addition, other species have been identified although they generally occurred in very small numbers (Table 2.2).

Genus	**Species**	**Common name**
Mollusca	**Gastropoda**	
Family Nassariidae	*Nassarius reticulatus*	Netted nassa
Family Buccinidae	*Buccinun undatum*	Buckie, common northern/edible European whelk
Family Littorinoidea	*Littorina littorea*	Edible/common periwinkle
Mollusca	**Bivalvia**	
Family Veneridae	*Polititapes aureus*	Golden carpet shell
	Tapes decussatus	Grooved carpet shell
Family Mytilidae	*Mytilus edulis*	Common blue mussel
Family Ostreidae	*Ostrea edulis*	Common European oyster
Family Cardiidae	*Cerastoderma edule*	Common European/edible cockle
Family Tellinidae	*Macoma balthica*	Baltic macoma

Table 2.2: Mollusc species identified at Havnø (Andersen 2008b; Madsen et al. 1900).

The stratigraphy demonstrated to the author that the shift from the EBK to the TRB was quick and within a short time span ca. 3950 cal BC (Andersen 2008b). Since kitchen middens are generally formed through the repeated deposition of smaller shell heaps it is often difficult to ascertain the relative age of the anthropogenic material. This is the current situation for the majority of the faunal assemblage. Thus, the associated ceramics, lithics, composition and shell size should be taken into consideration when there is a dearth of AMS radiocarbon dates on individual specimens themselves (Gron 2013a).

The anthropogenic material from the EBK layers is varied and includes the remains of fish, molluscs, marine and terrestrial mammals. The latter are characterised by forest dwelling ungulates that have been identified from many southern Scandinavian EBK assemblages (Andersen 2008b; Enghoff 2011; Gron 2013a). On the other hand, the TRB layers included a similar spectrum of species although they were recovered alongside the remains of domesticates.

In total, 1,365 avian and mammalians remains and 660 fish remains have been identified to

species or family level (Table 2.3). However, these values only concern the materials recovered from 2005-2011. There are 16 species of mammals, including four domesticates, 23 species of birds as well as 13 different families of fish represented in the faunal assemblage. In addition, some amphibians and rodents were recovered although they have been omitted since they are probably intrusive (Aaris-Sørensen and Andreasen 1992-1993; Gron 2013a; Ritchie 2010; Robson 2011; Robson *et al*. 2013). The faunal assemblage dating to the Neolithic is considered to be one of the largest, if not the largest in Denmark, perhaps southern Scandinavia (Andersen 2008b; Gron 2013a). In addition, the settlement debris included antler (Figure 2.10) and bone tools including bird bone awls/points, fishhooks, red deer T-axes and ulna daggers.

Figure 2.10: Photograph of two red deer antler pressure flakers. They were found below the shell midden sequence in 2011, and are thus dated to the EBK by association.

The pointed based vessels of the EBK and the funnel beakers of the TRB represent the ceramics. These were found alongside charcoal and lithics, for example core and flake axes as well as transverse arrowheads typical of the EBK, and polished flint axes of the TRB.

Potboilers have additionally been recovered. Two types of hearths have been identified, whereas pits and stakes holes are frequent throughout the kitchen midden. Overall the assemblage of anthropogenic materials recovered from Havnø is similar when compared with other stratified kitchen middens in Denmark, for example Bjørnsholm, Krabbesholm II, Norsminde and Visborg (Andersen 1989, 1991, 2000b, 2005).

Birds		**Mammals**		**Fish**	
Taxa	**NISP**	**Taxa**	**NISP**	**Taxa**	**NISP**
Velvet scoter	53	*Sus* sp.	394	European eel	477
Tundra swan	10	Ox	12	Garfish	11
Whooper swan	27	Auroch	1	Clupeidae	11
Cygnus sp.	38	*Bos* sp.	272	Bullhead/rock gunnel	2
Common scoter	4	Red deer	192	Gadidae	22
Ring ouzel	3	Grey seal	48	Atlantic cod	3
Common blackbird	3	Phocidae	38	Three-spined stickleback	54
Terdus sp.	3	Goat	21	Shorthorn sculpin	1
Greater scaup	3	Sheep	9	Pleuronectidae	39
Common pochard	2	Ovicaprid	75	Salmonidae	13
Aythya sp.	1	Dog	58	Atlantic mackerel	1
Red-breasted merganser	8	Roe deer	51	Scopthalmidae	1
Goshawk	4	Otter	5	Scorpaenids	2
Garganey	1	Beaver	3	Greater weever	21
Wigeon	1	Elk	2	Eelpout	2
Anas sp.	3	Fox	2	**Total**	**660**
Razorbill	2	Horse	1		
Common goldeneye	2	Wildcat	1		
Thrush nightingale	2	Pine marten	1		
Spotted nutcracker	2	**Total**	**1186**		
Great auk	2				
Little grebe	2				
Northern scoveler	2				
Common buzzard	1				
Smew	1				
Eurasian bullfinch	1				
Common murre	1				
Total	**182**				

Table 2.3: Relative abundance data for those materials excavated from 2005-2011 (Gron 2013a; Ritchie 2010; Robson 2010, 2011; Robson et al. 2013).

In addition, 52 human remains have been identified, and represent a minimum number of three individuals: one adolescent, one adult and one juvenile (Hellewell 2012a). Subsequent

diagenetic analysis has confirmed that at least two different burial practices appear to have taken place at the kitchen midden, and include excarnation and primary internment (Hellewell 2012b).

Noteworthy were the ca. 40 ‘pearls’ that were recovered from the EBK layers during the 2007 excavations at the kitchen midden. The shell buttons or pendants were represented by two forms that were either circular or oblong (Figure 2.11). They appeared to have been polished on their surface, and all possessed a groove around their circumference (Andersen 2008b). Interestingly similar buttons are only known from one other Danish EBK locality, the kitchen midden at Nederst that is situated on the Djursland peninsula, north central Jutland (Ritchie personal communication 2015). Although the species of mollusc has not been verified they are probably derived from the freshwater mussel (*Unio* sp. Demarchi personal communication 2015), and represent a new phenomenon for the EBK of Denmark.

Figure 2.11: The collection of ca. 40 shell buttons from the EBK layers at Havnø (after Andersen 2008b).

Initial observations have shown that there are characteristic and relative changes amongst the marine mollusc species present, as well as their size over time. At the very base of the kitchen midden there is a uniform layer of almost complete and large white-grey oysters (Figure 2.12). This horizon is a characteristic of the EBK and has been identified throughout a large proportion of the kitchen midden. Higher up in the midden sequence the horizons are represented by a combination of oyster, cockle, mussel and periwinkle. Although the relative abundance of the cockle increases in the TRB layers, it is still the

oyster that is the dominant species. In addition, the younger shell deposits are more crushed and the matrices are darker due to the higher content of charcoal and potboilers (Figure 2.13). However, it is essential to underline that the thickness of the shell layers varies across the kitchen midden (Andersen 2008b, personal communication 2013). Furthermore, the size of the oysters decreases diachronically. In the TRB layers the oysters are approximately half or two-thirds the size of those deriving from the EBK layers (Milner 2013; Robson *et al*. 2009). In addition, there is an increase in the number of deformed oysters in the younger horizons. This pattern is atypical and has been identified at other kitchen middens, for example Krabbesholm II and Norsminde (Laurie 2008; Milner 2002a; Milner and Laurie 2009). A potential explanation may be localised environmental changes or that the peoples were overexploiting the marine mollusc banks throughout the course of material deposition (Andersen 2008b).

Figure 2.12: The surface of the EBK layer at the bottom of the midden sequence characterized by a uniform horizontal layer of exclusively large and old oysters.

In short, Havnø is a particularly interesting kitchen midden for a number of reasons. It was

situated on what was once an isolated island, which indicates that people were probably making intentional trips across the water via a dugout canoe or sledge, depending upon the time of the year (Andersen 2008b; Gron 2013a). Secondly, the AMS radiocarbon dates demonstrate a particularly long period of use (Chapter 3), and may be partly explained by the favourable and stable biotope surrounding the island. Conceivably the island may have been frequented for the intentional deposition of human remains at the kitchen midden (Chapter 3) or for the exploitation of the shell banks (Chapter 4). Regarding the material culture, the transition from the EBK to the TRB appeared to have taken place over a very short period of time ca. 3950 cal BC. However, the economy probably gradually changed since hunting, gathering and fishing are represented in the Neolithic horizons at the kitchen midden. During the ENI the economy was probably based on an EBK way of life to the addition of domesticated fauna and flora (Andersen 2008b; Gron 2013a; Robson *et al*. 2013).

Figure 2.13: TRB layer with associated fauna and lithics. Note the darker matrices.

2.4. Sites sampled and examined in the study

In this study, material from a total of 33 Danish sites has been analysed and examined (Tables 2.4 and 2.5). Although some of the samples had been previously analysed, for example the ceramic sherds and food crusts from the submerged locality at Tybrind Vig (Chapter 5), it was deemed necessary to re-extract the lipids since the data were considered erroneous (Heron *et al*. 2013). In addition, it was considered appropriate to attempt new analyses, for example the ceramic sherd from the Åle kitchen midden (Chapter 5), and the adult individual interred at the Holmegård kitchen midden (Chapter 3), since the materials were available.

In this section a brief overview of these sites will be presented. Since the primary focus of the thesis is concerned with the Havnø kitchen midden, similar sites will be addressed first. This will be followed by other coastal localities including isolated find spots, submerged and waterlogged sites. A synthesis of the inland sites including the isolated 'bog pots' will conclude this chapter.

Site	SIA	IGLA	ORA	IA
Bjørnsholm		X	X	
Brovst		X		
Dyngby I		X		
Dyngby III		X		
Ertebølle		X		
Eskelund		X		
Eskilsø		X		
Gamborg Fjord			X	
Havnø	X	X	X	X
Holmegård	X	X		
Jorløse Mose VIII			X	
Jorløse Mose XV			X	
Jorløse Mose XX			X	
Kalvø		X		
Krabbesholm II		X		X
Lystrup Enge		X		
Maglelyng II			X	
Målevgårds Mose			X	
Norsminde		X		X
Øgårde kar A			X	
Ringkloster			X	
Ronæs Skov			X	
Roskilde Fjord			X	
Salpetermosen			X	
Stenø			X	
Teglgård-Helligkilde			X	
Thygeslund	X			X
Tybrind Vig		X	X	
Ulkestrup Lyng			X	
Vængesø III		X		
Visborg		X		
Åkonge			X	
Åle			X	

Table 2.4: Summary of the sites sampled and examined in the study, and the respective analyses performed. Key: SIA, stable isotope analyses, IGLA, incremental growth line analysis, ORA, organic residue analysis, IA, Ichthyoarchaeological analysis.

Site name	Year - excavator	Approximate dates (cal BC)	Epoch(s)	Site description
Bjørnsholm	1931 - H. C. Broholm	ca. 5050-4050	EBK	Kitchen midden
	1985 - 1992 - Søren H. Andersen & Erik Johansen	ca. 3960-3530	TRB	
Brovst	1969 - 1973 & 1976 - Søren H. Andersen	ca. 4600-4500	K-EBK	Kitchen midden
Dyngby I	1998 - Søren H. Andersen	ca. 4460-4340	EBK	Kitchen midden
Dyngby III	1995 - 2003 - Søren H. Andersen	ca. 4840-4260	EBK	Shell-bearing site
Ertebølle	1893 - 1897 - The Second Kitchen Midden Commission	ca. 5100-4100	EBK	Kitchen midden
	1979 - 1984 - Søren H. Andersen & Erik Johansen			
Eskelund	Søren H. Andersen	ca. 3970	EBK	Kitchen midden
Eskilsø	2000s - Søren Sørensen	ca. 4300-3800	EBK	Kitchen midden
		ca. 3800-3500	TRB	
Gamborg Fjord			EBK	Coastal isolated find spot
Havnø	1894 - The Second Kitchen Midden Commission	ca. 4540-1800	EBK-DC	Kitchen midden
	1995 & 2005 - 2013 - Søren H. Andersen			
Holmegård	1968 - Søren H. Andersen	ca. 5300-4500	EBK	Kitchen midden
Jorløse Mose VIII	1945	ca. 3300-2650	TRB	Isolated find spot
Jorløse Mose XV	1945	ca. 3950-3650	TRB	Isolated find spot
Jorløse Mose XX	1945	ca. 3950-2800	TRB	Isolated find spot

Site name	Year - excavator	Approximate dates (cal BC)	Epoch(s)	Site description
Kalvø	1963 & 1968 - 1975 - Søren H. Andersen	ca. 2480-2060	TRB-SGC	Kitchen midden
Krabbesholm II	2000 - 2004 - Søren H. Andersen	ca. 4800-4700	EBK	Kitchen midden
		ca. 3960-3330	TRB	
		ca. 2900-2300	SGC	
Lystrup Enge	1981 - 2005 - Søren H. Andersen	ca. 5700-4340	EBK	Waterlogged coastal site
Maglelyng II	1950s	ca. 3950-3550	TRB	Isolated find spot
Målevgårds Mose	1942 & 1944	ca. 3950-2800	TRB	Isolated find spot
Norsminde	1972 - 1989 - Søren H. Andersen	ca. 4700-4000	EBK	Kitchen midden
		ca. 4000-3500	TRB	
Øgårde kar A		ca. 3950-3650	TRB	Isolated find spot
Ringkloster	1969 - 1985 - Søren H. Andersen	ca. 5400-3550	EBK-TRB	Lakeshore settlement
Ronæs Skov	1992, 1997 - 1999 & 2001 - 2004 - Søren H. Andersen	ca. 4400-4000	EBK	Submerged site
Roskilde Fjord		ca. 3350-3100	TRB	Coastal isolated find spot
Salpetermosen		ca. 3350-2950	TRB	Isolated find spot
Stenø		ca. 4250-3950	EBK-TRB	Lakeshore settlement
Teglgård-Helligkilde			EBK	Submerged site
Thygeslund	2013 & 2014 - Søren H. Andersen	ca. 4460-3370	EBK-TRB	Kitchen midden

Site name	Year - excavator	Approximate dates (cal BC)	Epoch(s)	Site description
Tybrind Vig	1978 - 1987 - Søren H. Andersen	ca. 5400-4000	EBK	Submerged site
Ulkestrup Lyng	1949	ca. 3300-2650	TRB	Isolated find spot
Vængesø III	1998, 2003 - 2005 - Søren H. Andersen		EBK-TRB	Kitchen midden
Visborg	1888 - A. P. Madsen	ca. 4800-3200	EBK-TRB	Kitchen midden
	1995 - 2002 - Søren H. Andersen			
Åkonge	1984 - 1985 - National Agency	ca. 4250-3670	EBK-TRB	Lakeshore settlement
Åle	1987 - 1989 - Søren H. Andersen	ca. 5210-3980	EBK	Kitchen midden
		ca. 3950-3100	TRB	

Table 2.5: Summary data of the archaeological sites from which materials were examined or sampled from.

2.4.1. The kitchen midden and shell-bearing sites

Including Havnø a total of 16 kitchen midden and shell-bearing sites were analysed and examined in the study (Figure 2.14). While the majority of the sites were located on the Jutland peninsula, there was one kitchen midden that was situated on Zealand, Eskilsø.

2.4.1.1. Bjørnsholm

Bjørnsholm is a kitchen midden that is located <10 km north of the Ertebølle kitchen midden in the Limfjord, northern Jutland. It was initially excavated in 1931 under the direction of H. C. Broholm, and then revisited under the direction of Søren H. Andersen and Erik Johansen from 1985 to 1992. It is one of the so-called stratified kitchen middens with the EBK layers dating from ca. 5050-4050 cal BC, whereas the TRB layers have been dated from ca. 3960-3530 cal BC (Andersen 1991). The anthropogenic material has been interpreted as a reflection of numerous home base activities, and included the recovery of ceramics, faunal remains, lithics as well as worked antler and bone. The faunal remains

were represented by wild boar, red deer and roe deer, which were supplemented by marine mammals, carnivores and birds (Bratlund 1991). The fish remains were dominated by the European eel that was supplemented by Gadidae (Enghoff 1991).

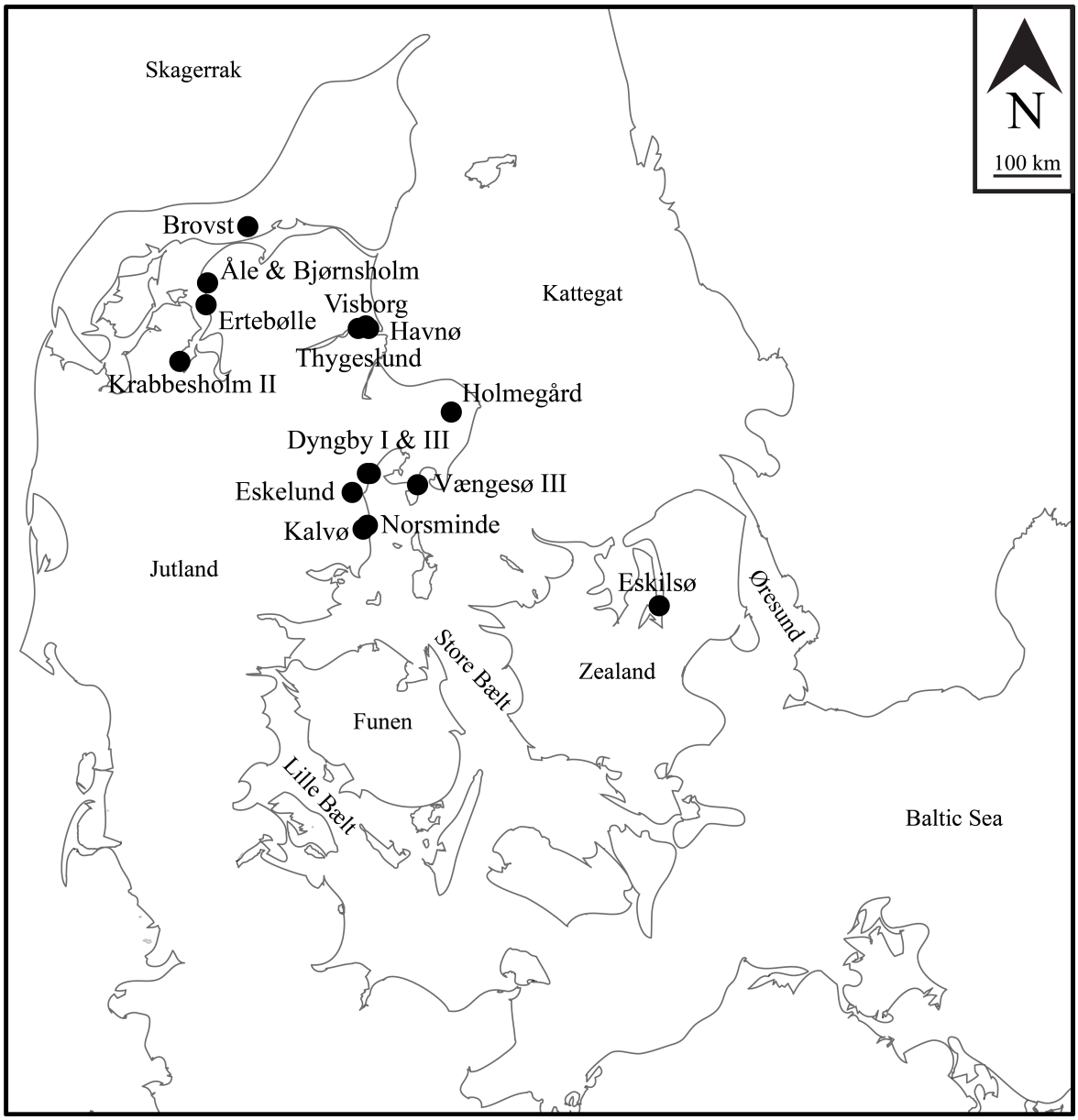


Figure 2.14: Map showing the locations of the kitchen midden and shell-bearing sites that were sampled or examined in the study.

2.4.1.2. Brovst

The coastal settlement at Brovst (also referred to as Bratskov and North Skovsgaard) is

situated on the island of Mors, north of the Limfjord in northern Jutland. It was excavated under the direction of Søren H. Andersen in collaboration with Aalborg Historical Museum from 1969 to 1973, as well as 1976 following the discovery of human remains from 1964 (Newell *et al*. 1979). In total 150 m^2 were investigated yielding a coastal settlement that also had a shell layer at the locality (Newell *et al*. 1979). It is perhaps the oldest kitchen midden in Denmark with anthropogenic material dating to the Kongemose culture at the very bottom of a stratified sequence of layers (Andersen personal communication 2013). In the upper layer, which was primarily composed of isolated shell heaps, material culture from the EBK was recovered, including antler, bone, ceramics, charcoal and lithics (Andersen 1970; Tauber 1973). The oyster shell samples analysed in this study (Chapter 4) derived from layer 4 that has been dated to the middle EBK, ca. 4600-4500 cal BC (Andersen personal communication 2013).

2.4.1.3. Dyngby I

Dyngby I is a kitchen midden and one of five small EBK sites located on the eastern coastline of central Jutland. It was excavated under the direction of Søren H. Andersen in 1998. The kitchen midden is ca. 12 m long by ca. 10 m wide with a maximum depth of ca. 30 cm. The anthropogenic material included faunal remains and lithics that have been dated from ca. 4460-4340 cal BC (Andersen personal communication 2013; Milner 2002a).

2.4.1.4. Dyngby III

Dyngby III is a coastal site represented by a number of small shell heaps, *sensu stricto* a shell bearing site. It is located <1 km north east of the Dyngby I kitchen midden in central Jutland. It was excavated intermittently under the direction of Søren H. Andersen from 1995 to 2003 (Figures 2.15 and 2.16). The coastal settlement is ca. 10 m long by ca. 10 m wide. The material culture is represented by ceramics, charcoal, faunal remains including pig, oxen, roe deer and red deer as well as lithics and potboilers. The anthropogenic material demonstrated to the author that the site had a restricted and specialised use and had been revisited repeatedly over several centuries during the EBK. Based on two AMS radiocarbon dates the site has been dated from ca. 4840-4260 cal BC (Andersen 2004b, personal communication 2013).

Figure 2.15: Overview of excavations at Dyngby III in July 2003 (photograph courtesy of Nicky Milner).

Figure 2.16: Section exposed at Dyngby III in July 2003 (photograph courtesy of Nicky Milner).

2.4.1.5. Ertebølle (locus classicus)

The Ertebølle kitchen midden is the type-site for the EBK culture, and is situated <10 km south of the Bjørnsholm kitchen midden in the Limfjord, northern Jutland. It was initially excavated from 1893 to 1897 by *The Second Kitchen Midden Commission*, and then revisited under the direction of Søren H. Andersen and Erik Johansen from 1979 to 1984 (Figure 2.17) (Andersen and Johansen 1986; Madsen *et al*. 1900). Based on a series of 26 AMS radiocarbon dates the kitchen midden essentially encompasses the entire chronological range for the EBK, from ca. 5100-4100 cal BC (Andersen and Johansen 1986, Gutiérrez-Zugasti *et al*. 2011). The anthropogenic material included antler, bone, ceramics, charcoal and lithics. The faunal assemblage was predominantly composed of roe

deer, red deer, and swine although fur-bearing mammals, marine mammals represented by cetaceans and seals, as well as birds were identified (Enghoff 2011). A small spring was recorded at the site, whereas a couple of freshwater lakes were identified in the hinterland (Petersen 1986). The numerous remains of freshwater species of fish attest to the exploitation of the latter, although fishing for the European eel was the primary focus (Enghoff 1986). In addition, a natural shell bank was also recorded between 200 and 300 west of the kitchen midden that was intensively exploited (Petersen 1986). The preliminary analysis demonstrated to the authors that the kitchen midden had been organised into specific areas (Andersen and Johansen 1986). Furthermore, daily routines were probably undertaken on the kitchen midden throughout the course of accumulation in a rather stable settlement system (Andersen and Johansen 1986).

2.4.1.6. Eskelund

Eskelund is a kitchen midden located on the eastern coastline of central Jutland at Brabrand Sø, a prehistoric fjord. It was once situated on the west end of a small island, which has subsequently been completely destroyed and covered by a landfill site. It was partially excavated by Søren H. Andersen in collaboration with Forhistorisk Museum over a 20-year period. The kitchen midden is ca. 50 m long by ca. 25 wide with a maximum depth of ca. 10-15 cm. Eskelund is awaiting publication, and belongs to the late/younger EBK, ca. 3970 cal BC (Andersen personal communication 2014; Milner 2002a).

2.4.1.7. Eskilsø

Eskilsø is a small kitchen midden that is located on the northeast coastline of a small island (known as Eskilsø) in the Roskilde Fjord, north Zealand, east Denmark. It was discovered following a survey that resulted in the identification of more than 100 kitchen middens along the palaeoshorelines of the fjord. It was partially excavated by Søren Sørensen in the 2000s, which demonstrated that there was not only a single but two closely spaced shell heaps at the site, one of which was dated to the Neolithic. Although Eskilsø is awaiting publication, the latest EBK layer has been typologically dated from ca. 4300-3800 cal BC, whereas the subsequent TRB layer from ca. 3800-3500 cal BC. In addition, artefacts dating from the Neolithic SGC and PWC cultures were recovered (Sørensen 2000, personal

communication to Nicky Milner 2001).

Figure 2.17: Overview of excavations at Ertebølle in 1980 (after Gutiérrez-Zugasti et al. 2011, figure 2).

2.4.1.8. Holmegård

The kitchen midden at Holmegård is located on the southeastern part of the Djursland peninsula, east central Jutland. Following the discovery of an inhumation grave by R. Whallin in 1967 emergency excavations were undertaken the following year under the direction of Søren H. Andersen (Andersen and Vedsted 1986; Newell *et al*. 1979). Since the site was threatened by ploughing, excavation of the inhumation burial (Figure 2.18) and

a part of the kitchen midden was carried out. Overall 13 m^2 were excavated. The shell heap measures approximately 30 x 20 m and had a maximum thickness of 0.5 m (Andersen and Vedsted 1986; Andersen *et al*. 1986; Newell *et al*. 1979). The partial excavations yielded circular stone hearths, ash coloured deposits and irregular large stones as well as secondary pits and numerous disturbances. In the shell layer some material culture was recovered, although an activity area was found which included an area of lithics as well as charcoal and potboilers associated with hearths (Andersen and Vedsted 1986). In total, eight fish bones deriving from the genus Gadidae were identified by the author, which were recovered from within the fill of the burial. Anthropogenic material and a direct AMS radiocarbon date suggests a chronological age for the midden from ca. 5300-4500 cal BC (Andersen personal communication 2013). An AMS radiocarbon date on the human individual produced a date of 6057 ± 64 cal BP (OxA-533/K-3559) (Gillespie *et al*. 1984; Andersen *et al*. 1986), which was subsequently corrected by Fischer *et al*. (2007) to 5719 cal BP. The author has corrected this date using the criteria outlined in Chapter 3 from 4590 to 4500 cal BC, coincidentally the EBK.

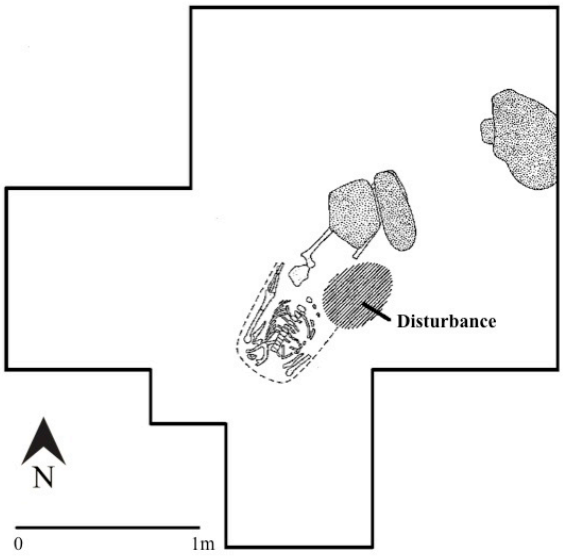


Figure 2.18: Plan of the inhumation burial at the Holmegård kitchen midden (image modified from the original, courtesy of Søren H. Andersen).

2.4.1.9. Kalvø

Kalvø is a kitchen midden that is situated on what was once an island (ca. 200 x 100 m) in Norsminde Fjord, east central Jutland (Figure 2.19). It was excavated under the direction of

Søren H. Andersen in 1963, 1968 and 1975. It is a small kitchen midden, ca. 8 m long by ca. 8 m wide with a maximum depth of ca. 40 cm, which had a stratigraphical sequence from the TRB that was overlain by material culture from the SGC. It is the only kitchen midden in the whole of southern Scandinavia with organic remains from this culture. The anthropogenic material included antler, bone, ceramics, charcoal, and potboilers that demonstrated to the author that the site was restricted to a limited number of small visits (Andersen 1983). The faunal assemblage was represented by domesticated and wild animals, and was predominantly composed of domesticated cattle that were primarily exploited for their meat (Enghoff 2011; Rowley-Conwy 1985b). In addition, waterfowl and fish remains were recovered, the latter dominated by the genus Gadidae (Enghoff 2011). Based on one AMS radiocarbon date the kitchen midden has been dated from ca. 2480-2060 cal BC (Andersen 1983).

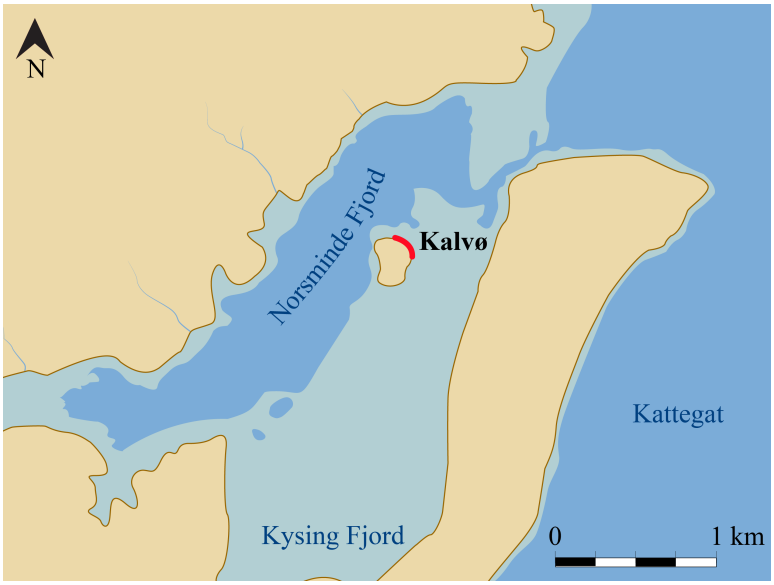


Figure 2.19: Map of the Norsminde Fjord showing the location of the Kalvø kitchen midden. Key: cream, dry land throughout prehistory, light blue, Littorina Sea, dark blue, present day sea (redrawn and modified from Andersen 1983, figure 1).

2.4.1.10. Krabbesholm II

Krabbesholm II is the second of two kitchen middens located in the southern Limfjord, northern Jutland. It was excavated under the direction of Søren H. Andersen in collaboration with John Simonsen of Skive Museum from 2000-2004. It is one of the so-called stratified kitchen middens with EBK layers dating from ca. 4800-4700 cal BC overlain by TRB layers dating from ca. 3960-3330 cal BC. Interestingly, site use continued

into the SGC that has been dated from ca. 2900-2300 cal BC. Anthropogenic material included ceramics, charcoal, lithics and potboilers (Figure 2.20). In general, tools made from antler and bones are rare. The faunal assemblage was represented by fur bearing, marine as well as domesticated and wild mammals, including swine, roe deer, red deer, cattle, and ovicaprid (*Ovis/Capra* sp.). Overall, bird remains are rare, although fish remains were frequently encountered, which were dominated by the European eel and followed by the three-spined stickleback (*Gasterosteus aculeatus*) (Andersen 2005; Enghoff 2011; Laurie 2008; Milner 2001a, 2013; Milner and Laurie 2006; Nielsen 2007a, 2007b, 2008, 2009).

Figure 2.20: A localised deposition of cockleshells intermixed with a potboiler (photograph courtesy of Nicky Milner).

2.4.1.11. Norsminde

Norsminde is a kitchen midden that is located in the Norsminde Fjord in north central Jutland (Figure 2.21). It was excavated under the direction of Søren H. Andersen in collaboration with Geoff Bailey from 1972 to 1989. It is one of the so-called stratified kitchen middens with the EBK layers dating from ca. 4700-4000 cal BC, whereas the TRB layers have been dated from ca. 4000-3500 cal BC. Although it is a stratified kitchen midden it has been difficult to prove whether occupation was continuous or not. It was systematically excavated and may be rated as totally excavated. The anthropogenic material has been interpreted as reflecting numerous home base activities at the site. Ceramics were

found alongside faunal remains, lithics as well as worked antler and bone. The faunal assemblage encompassed both domesticated and wild mammals as well as birds, whereas the fish remains were dominated by Pleuronectidae, especially European flounder that was supplemented by Gadidae and European eel (Andersen 1989; Enghoff 1989; Froom 1979).

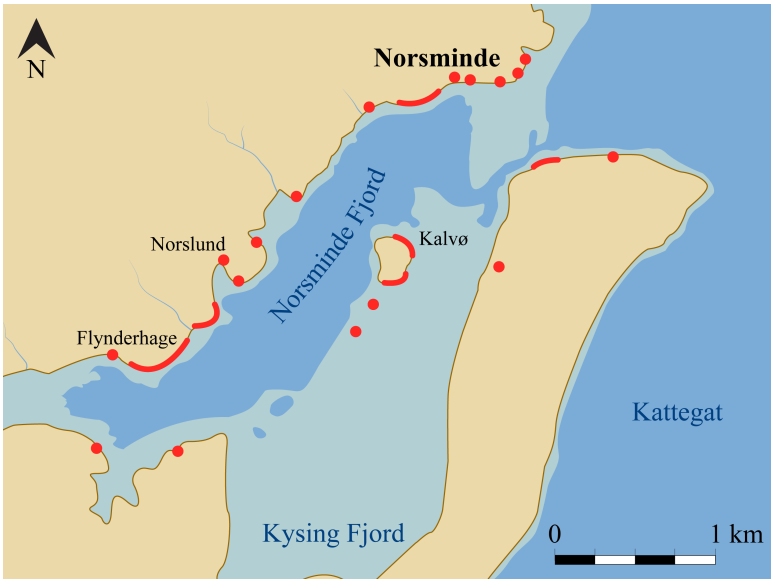


Figure 2.21: Map of the Norsminde Fjord showing the location of the Norsminde kitchen midden as well as other EBK, TRB and SGC sites along the former coastlines. Key: cream, dry land throughout prehistory, light blue, Littorina Sea, dark blue, present day sea (redrawn and modified from Andersen 1989, figure 1).

2.4.1.12. Thygeslund

The Thygeslund kitchen midden is located on the north coast of the Mariager Fjord, on the eastern coast of north central Jutland. It is situated <5 km away from the contemporaneous kitchen middens at Havnø and Visborg (Figure 2.22). It was excavated under the direction of Søren H. Andersen in 2013 and 2014. In total, 4 m^2 have been excavated. While brushwood and trees cover the majority of the site, a portion of the kitchen midden was destroyed in the 1800s when the farm at the site was built. It has been estimated that the kitchen midden is ca. 50-60 x 50-60 m in size although it is probably larger, and greater than the Havnø kitchen midden. In general, the midden sequence is rich in terms of anthropogenic material. The faunal assemblage is represented by red deer, roe deer, wild boar, wildcat, *Bos* sp, and whooper swan (*Cygnus cygnus*). The material has been dated from the EBK to the TRB cultures based on three AMS radiocarbon dates, from ca. 4460-3370 cal BC (Andersen personal communication 2013-2015; Gron personal communication 2014-2015).

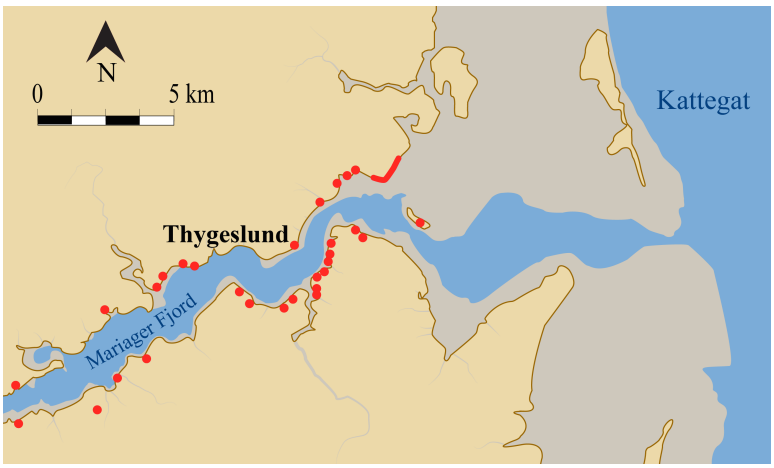


Figure 2.22: Map of the Mariager Fjord showing the location of the Thygeslund as well as other kitchen middens demarcated by red dots. Key: cream, dry land throughout prehistory, grey, Littorina Sea, blue, present day sea (redrawn and modified from Andersen 2008b, figure 1).

2.4.1.13. Vængesø III

Vængesø III is one of four coastal sites located on the Helgenæs peninsula in east central Jutland. Unfortunately the majority of the kitchen midden has been completely destroyed by ploughing. It was excavated under the direction of Søren H. Andersen in 1998 and then from 2003-2005. Based on four AMS radiocarbon dates together with the anthropogenic material (Figure 2.23), the kitchen midden belongs to the EBK that is overlain by a very thin TRB layer. Interestingly, traces of three possible dwellings have been identified. The faunal assemblage encompassed marine and terrestrial mammals, dominated by seal, numerous species of birds including cormorant (*Phalacrocorax carbo*) and fish remains that were comprised of the European flounder, plaice (*Platessa platessa*) and Gadidae, especially cod (Enghoff 2011).

Figure 2.23: Excavated hearth at the Vængesø III kitchen midden (taken from http://videnskab.dk/miljo-naturvidenskab/sadan-spiser-du-osters-som-en-stenaldermand).

2.4.1.14. Visborg

The Visborg kitchen midden is situated on the north coastline of the Mariager Fjord on the eastern coast of north central Jutland. It was initially excavated by A. P. Madsen in 1888 and was re-excavated under the direction of Søren H. Andersen from 1995-2002 (Figures 2.24 and 2.25). It is the largest kitchen midden in Denmark, ca. 600-700 long by 30-35 m wide. Unfortunately the majority of the site has been ploughed away, thus ca. 20-30 cm of the kitchen midden sequence is *in situ*. Visborg is one of the so-called stratified kitchen middens, and has been dated from ca. 4800-3200 cal BC. While it is awaiting publication, the faunal assemblage has been analysed, which was represented by fish remains, primarily Gadidae, bird bones dominated by swan, as well as marine and terrestrial animals, including domesticates and fur bearing mammals (Andersen 2000b; Enghoff 2011; Milner 2002a).

Figure 2.24: Overview of excavations at the Visborg kitchen midden in 1999 (photograph courtesy of Nicky Milner).

2.4.1.15. Åle

Åle is a kitchen midden that is located in the Bjørnsholm inlet in the Limfjord, northern Jutland. It is considered an extension of the Bjørnsholm kitchen midden, which is ca. 150 m long by ca. 25 m wide. It was excavated under the direction of Søren H. Andersen from 1987-1989. While it is considered one of the so-called stratified kitchen middens, differentiation between the EBK and TRB contexts has, at times, proven to be difficult. The EBK layers of the kitchen midden have been dated from ca. 5210-3980 cal BC, whereas the

TRB from ca. 3950-3100 cal BC. Mammals identified in the faunal assemblage included red deer, roe deer and swine. In addition, domesticated, fur bearing and marine fauna were present (Andersen 1991; Enghoff 2011).

Figure 2.25: Overview of excavations at the kitchen midden at Visborg in 1999. Note the two sections that were left in situ during excavation (photograph courtesy of Nicky Milner).

2.4.2 Coastal isolated find spots

Ceramic vessels recovered from two coastal isolated find spots were examined and sampled in the study: Gamborg Fjord that is situated off the west coast of the island of Funen and Roskilde Fjord that is located in north eastern Zealand (Figure 2.26).

2.4.2.1. Gamborg Fjord

In total, there are 13 sites situated in Gamborg Fjord. Except for one, all date to the EBK. In this study, one isolated vessel recovered from the seabed in Gamborg Fjord was analysed (Andersen 2009) (Chapter 5).

2.4.2.2. Roskilde Fjord

Similarly one isolated underwater vessel recovered from Roskilde Fjord was integrated into

the present study (Chapter 5). Based on one AMS radiocarbon date from the food crust on the interior of the vessel it is dated to the TRB, ca. 3350-3100 cal BC (Craig *et al*. 2011; Koch 1998).

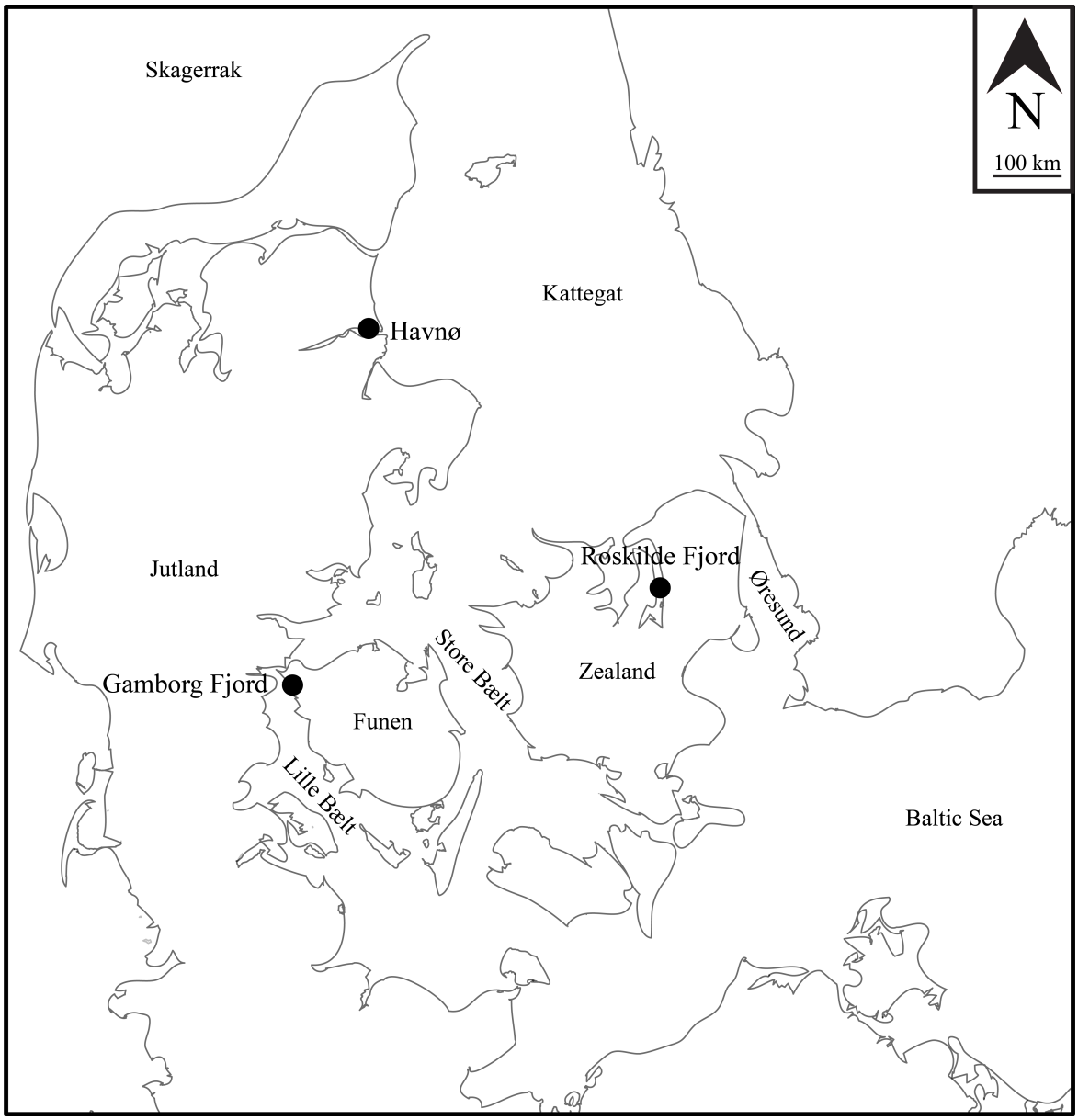


Figure 2.26: Map showing the locations of the coastal isolated find spots that were sampled or examined in this study.

2.4.3. Submerged sites

In total three localities that are presently submerged were examined and sampled in the

study (Figure 2.27). The three sites are all situated off the west coast of the island of Funen.

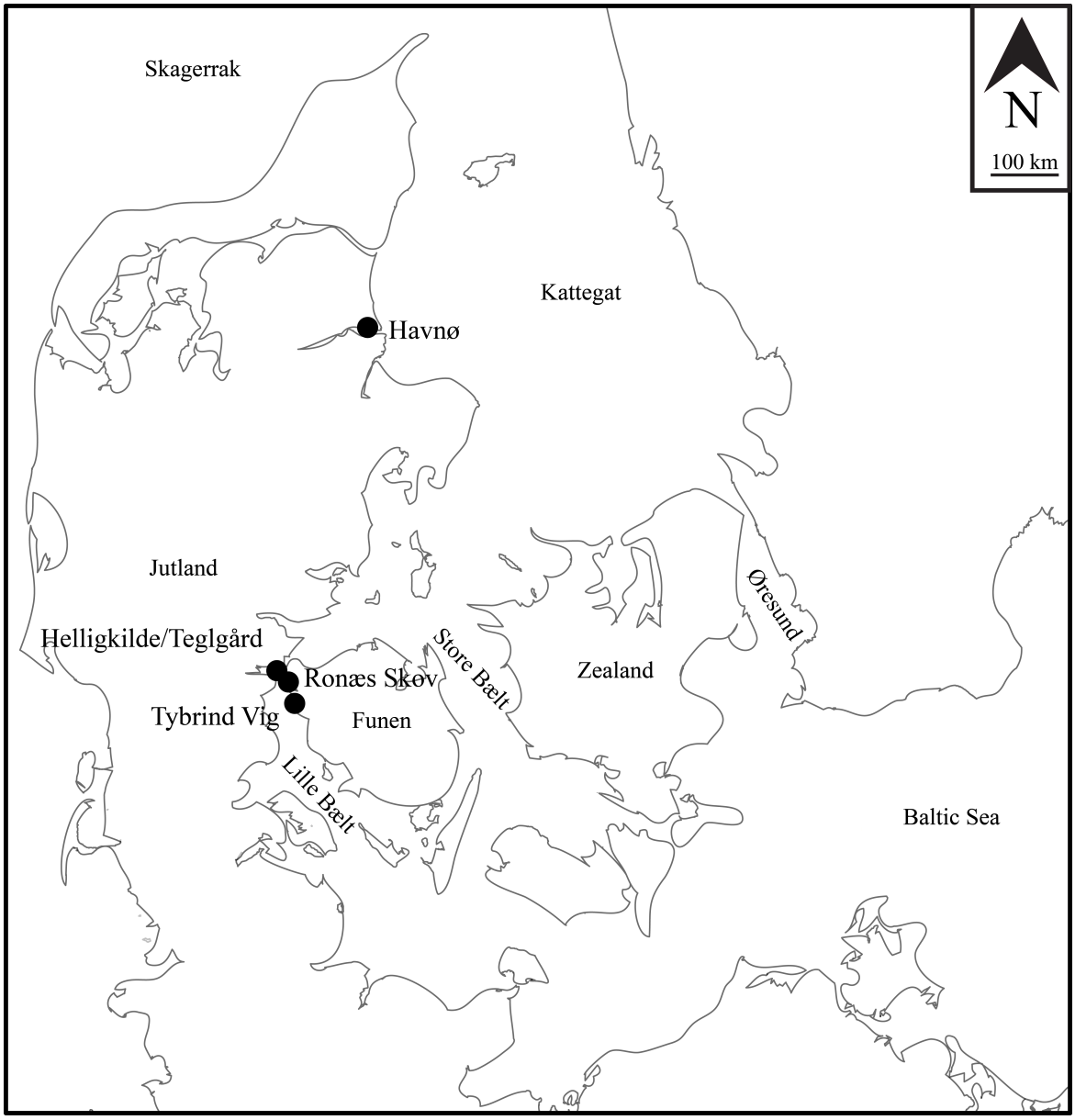


Figure 2.27: Map showing the locations of the submerged sites that were sampled or examined in the study.

2.4.3.1. Ronæs Skov

Ronæs Skov is a submerged coastal settlement that is located in Gamborg Fjord off the west coast of the island of Fyn. Throughout prehistory it would have been situated on the southern side of a promontory that extended into the Little Bælt. It was excavated under the direction of Søren H. Andersen in 1992, 1997-1999, and from 2001-2004. It has been

solely dated to the EBK, from ca. 4400-4000 cal BC. Ronæs Skov has a very diverse and rich anthropogenic assemblage that is composed of antler, bone, ceramics, charcoal, lithics, plant remains, potboilers, and wood. The faunal assemblage included terrestrial and fur-bearing mammals that were predominantly composed of wild boar, red deer, pine marten and wildcat respectively. Dog (*Canis familiaris*) was the only domesticate. Marine mammals were represented by seal, porpoise, dolphin and whales, whereas bird remains are few. Atlantic cod, spurdog and Salmonidae dominated the fish remains. Marine molluscs were also recovered. The locality is renown for its rich assemblage of worked wood, bark and withies that included, leister prongs, sharpened hazel wood sticks that have been interpreted as degraded fishing structures, shafts, spears, axe handles, bows, paddles, fragments of dugout canoes (Figure 2.28) and handles for mortars. In addition, it is the richest EBK settlement in terms of the ceramics that were recovered. Furthermore, at least three hearths and a series of stepping-stones, the latter for access into the reed area in front of the site were excavated. Overall, it has been interpreted as a base settlement with traces of intermittent periods of occupation throughout the year (Andersen 2009).

Figure 2.28: Photograph of one of the dugout canoes from Ronæs Skov (after Andersen 2009, figure 101).

2.4.3.2. Teglgård-Helligkilde

Teglgård-Helligkilde is a large coastal settlement that is similarly situated in Gamborg Fjord, off the west coast of the island of Fyn. It is contemporaneous with both Ronæs Skov and Tybrind Vig, and is presently submerged. Marine mammals, including numerous porpoise remains have been recovered (Andersen 2009).

2.4.3.3. Tybrind Vig

The submerged coastal settlement at Tybrind Vig is located off the west coast of the island of Fyn in the Little Bælt. During prehistory it would have been situated on the shoreline. Tybrind Vig was discovered in 1975 following consistent erosion and extensive degradation of eelgrass on the seabed. Excavations under the direction of Søren H. Andersen were undertaken every summer from 1978-1987. It has been solely dated to the EBK, from ca. 5400-4000 cal BC, and is perhaps most renowned for its rich assemblages of artefacts made of organic materials. Numerous paddles, some of which had carved images/patterns inlaid with black pigment were recovered. In addition, three dugout canoes as well as tools and weapons were found, including bows, arrows, axe handles, and leister prongs. Furthermore, several graves (Figure 2.29) were discovered alongside antler, bone, ceramics, lithics, plant remains, and a phenomenon not previously encountered – knitted textiles made from bast and plant fibres (Andersen 1985, 1986, 2011b, 2013b; Uldum 2011).

Figure 2.29: Photograph of the inhumation burial that included a young female (15-17 years of age at death) and a neonate (http://www.dandebat.dk/dk-historie7.htm - accessed 12/05/2015).

2.4.4. Waterlogged coastal sites

Only one waterlogged coastal site was examined and included in the study (Figure 2.30).

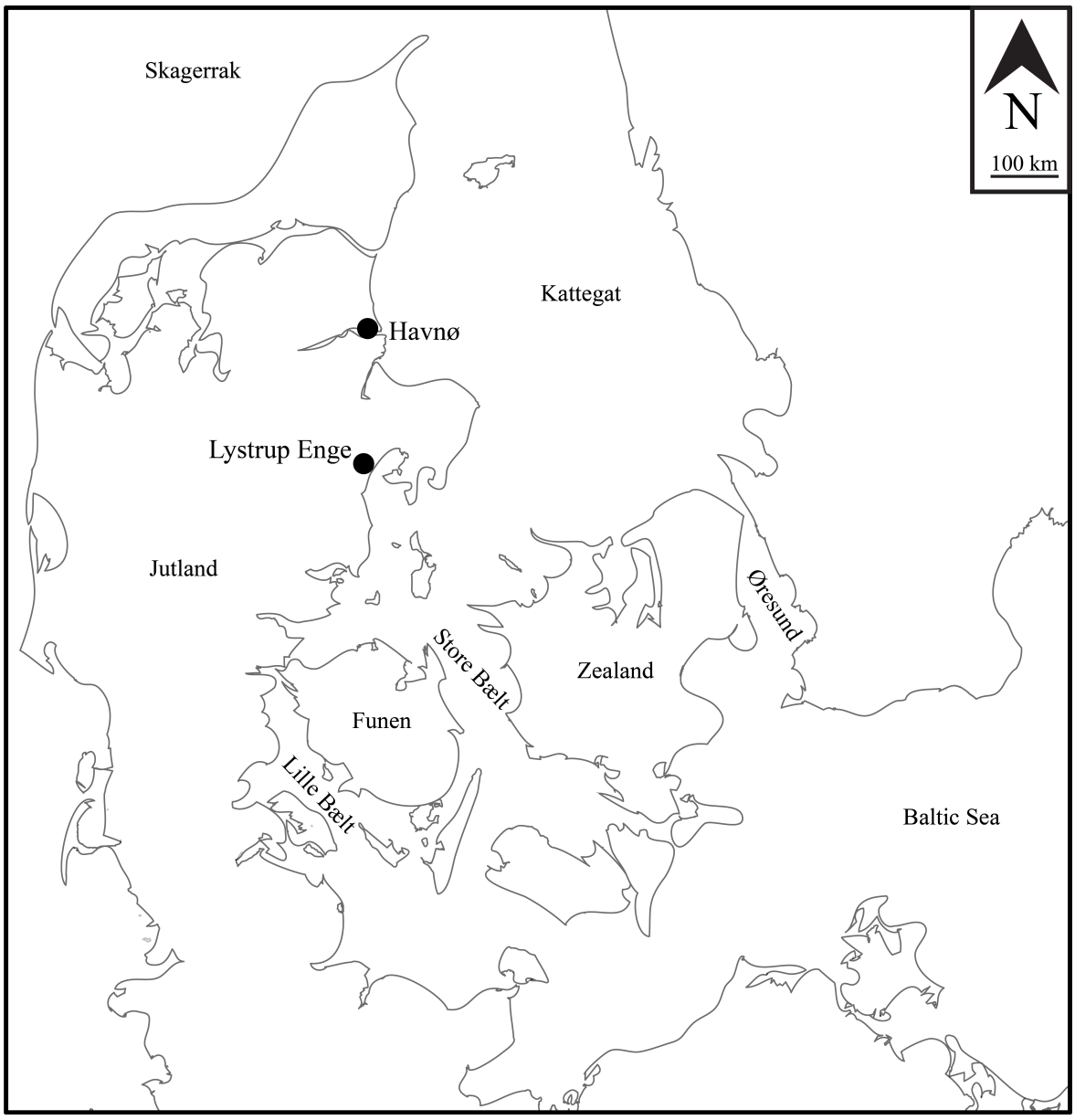


Figure 2.30: Map showing the location of the waterlogged coastal site at Lystrup Enge.

2.4.4.1. Lystrup Enge

Lystrup Enge is a coastal settlement that is situated in an inner inlet that opened into Århus Bugt, on the east coastline of north central Jutland. Throughout prehistory it would have been located on a sand-gravel bar that was presumably separated from the coast by an inner-tidal lagoon. It was excavated under the direction of Søren H. Andersen in collaboration with B. and P. E. Damsgård from 1981-2005, and has been dated from ca. 5700-4340 cal BC, thus the older EBK. Surprisingly, the site encompassed a refuse zone in

front of a settlement area as well as the remains of a re-deposited kitchen midden. To the east of the site a brook has been identified. While it is awaiting publication, the faunal remains as well as the EBK dugout canoes have been summarised (Andersen 1996, 2011b; Enghoff 1994, 2011). In the refuse zone, a total of 558 pointed hazel wood sticks interpreted as the remains of a degraded fishing structure as well as two dugout canoes were recovered. On the other hand, the kitchen midden was ca. 100 m long, 10 m wide and ca. 10 cm thick. Despite the fact that >3500 m^2 have been excavated only a thin cultural layer (ca. 5-20 cm) remained *in situ*. The fish remains were predominantly composed of Gadidae, which was followed by Pleuronectidae. Interesting, the remains of porbeagle (*Lamna nasus*) and tope shark (*Galeorhinus galeus*) were identified. Although numerous bird bones and fur bearing mammals were recovered, the faunal assemblage was dominated by red deer, which was followed by wild boar, auroch, roe deer and elk. Furthermore, numerous cetacean bones were found alongside charcoal and tools made from antler and bone (Andersen 1996, 2011b; Enghoff 1994, 2011).

2.4.5. Inland localities and isolated find spots

A total of 11 inland sites and isolated find spots were examined in the present study (Figure 2.31). While the majority of the samples were derived from isolated find spots in the Store Åmose complex in northwestern Zealand, some were recovered from *in situ* contexts, for instance Stenø and Åkonge. Only one inland locality on the Jutland peninsula was represented in the sample set, the lakeshore settlement at Ringkloster.

2.4.5.1. Jordløse Mose VIII

Jordløse Mose VIII is a ca. 50 m wide belt of one of the former inland lakes in the Lille Åmose on the island of Zealand. A total of 11 artefacts were recovered together that were delivered to the National Museum in Copenhagen in 1945. The majority of the artefacts were represented by complete vessels that had been intentionally deposited in the former lake. The site is presently a peat bog. Although they were recovered from different depths within the peat, they were typologically similar. The variability in depth has been interpreted as reflecting the unevenness of the former lake at the time of material deposition. Based on one AMS radiocarbon date on the interior food crust from one vessel,

the cache is dated to the TRB, ca. 3300-2650 cal BC (Craig *et al*. 2011; Koch 1998).

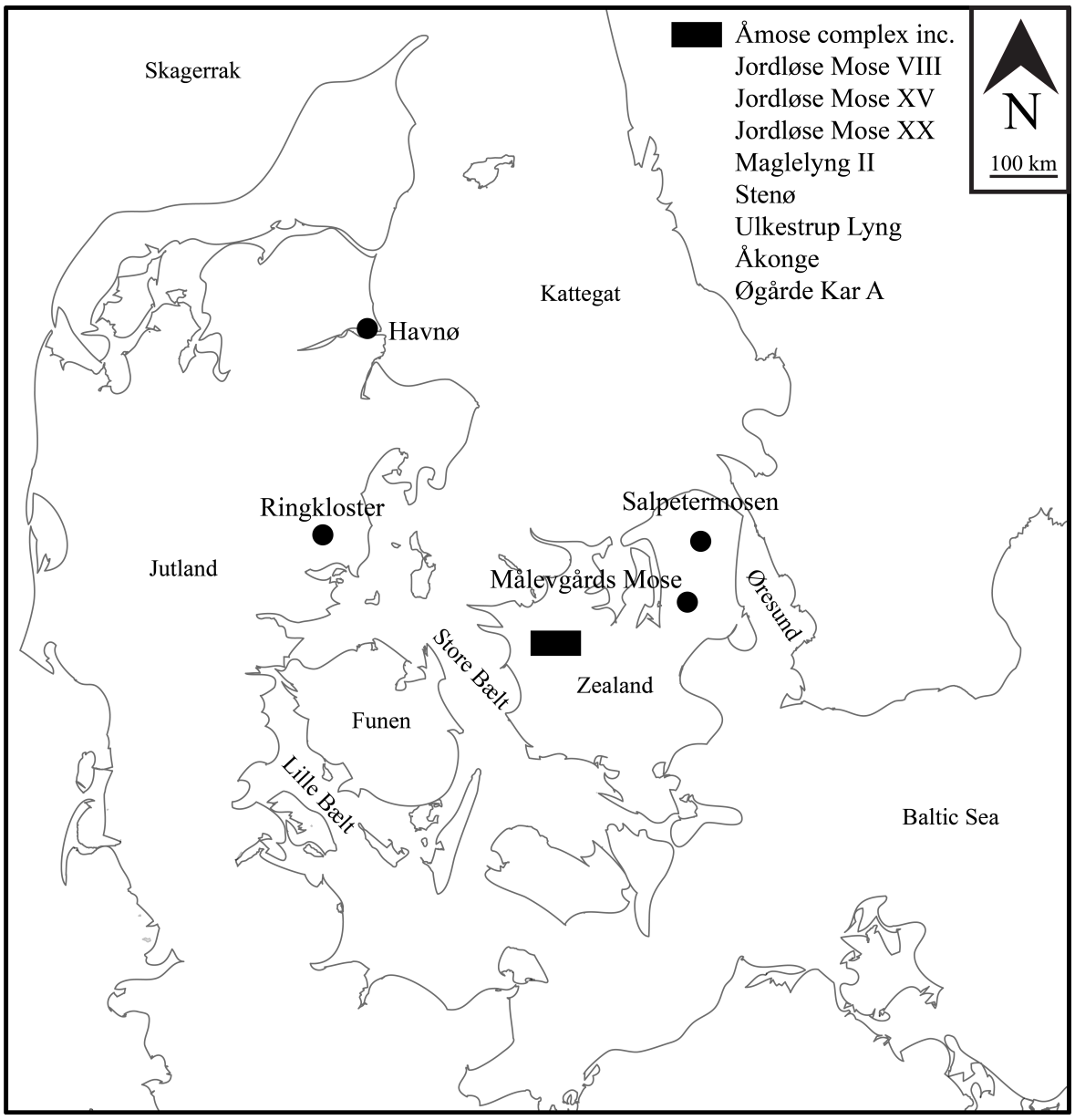


Figure 2.31: Map showing the location of the inland localities and isolated find spots that were examined in the study.

2.4.5.2. Jordløse Mose XV

Jordløse Mose XV is similarly another find spot opposite Egebjerg in one of the former inland lakes in the Lille Åmose on the island of Zealand. In total, one complete funnel beaker as well as four sherds were found in the peat bog. The complete vessel was found

standing on its base at a depth of ca. 2 m, whereas the sherds were found close by at the same locality. In addition, a flint drill and tanged arrowhead were found in the same cutting. It would appear that all artefacts had been intentionally deposited into the former lake. The intact funnel beaker was delivered to the National Museum in 1945. Based on one AMS radiocarbon date on the interior food crust from the complete vessel, the cache is dated to the TRB, ca. 3950-3650 cal BC (Craig *et al*. 2011; Koch 1998).

2.4.5.3. Jordløse Mose XX

Likewise Jordløse Mose XX is another area in one of the former inland lakes in the Lille Åmose on the island of Zealand. Overall, three intact vessels, six sherds, two thin-butted axes, and a blade scraper were found. All artefacts were recovered from the fen peat or gyttia alongside freshwater molluscs at a depth of between ca. 0.70-1.35 m. They had been intentionally deposited into the former lake and were delivered to the National Museum in 1945. The cache has been dated to the TRB, ca. 3950-2800 cal BC (Koch 1998).

2.4.5.4. Maglelyng II

Maglelyng II is situated in one of the former inland lakes in the Store Åmose on the island of Zealand. In the 1950s labourers recovered one complete medium sized funnel beaker and a lugged flask during cultivation and peat cutting. C. Strømberg delivered the vessels to the National Museum in 1963. Both vessels were found standing ca. 4-5 m apart at a depth of ca. 1 m below the topsoil. The funnel beaker was discovered standing on the end of a split piece of alder wood, whereas pike remains were present on the opposing side. In addition, a greenstone axe measuring ca. 24 cm in length was found not far away. All three artefacts had been intentionally deposited into the former lake. Based on one AMS radiocarbon date on the interior food crust from one of the vessels, the cache is dated to the TRB, ca. 3950-3550 cal BC (Craig *et al*. 2011; Koch 1998).

2.4.5.5. Målevgårds Mose

Målevgårds Mose is located in what was once a small lake that had been formed by the widening of a stream on the island of Zealand. In total, an ornamented slender lugged beaker, and an ornamented funnel bowl were recovered. Since they were discovered some

distance apart they may have been deposited separately into the former lake. The site is presently a peat bog. The vessels were gifted to the National Museum in 1942 and 1944 by the merchant Skovdal-Nielsen, Jørgen Birch and Co.'s successor. The cache has been dated to the TRB, ca. 3950-2800 cal BC (Koch 1998).

2.4.5.6. Ringkloster

Ringkloster is a lakeshore settlement that is situated on the shore of a prehistoric peninsula in the former Lake Skanderborg, central Jutland. It is the largest of several sites around the edge of the former lake (Andersen 1994-1995). It was excavated under the direction of Søren H. Andersen from 1969-1985 (Enghoff 2011). The site encompassed a settlement area on dry land with numerous structural remains, including hearths, pits and postholes, as well as a refuse zone in front of the settlement in the former lake. A rich assemblage of faunal remains and organic materials were found in this area of the site. The faunal assemblage was predominantly composed of wild boar, red deer and auroch, although fur-bearing mammals were also recovered (Rowley-Conwy 1994-1995). Dog remains were the only domesticate at the site. In addition, tools made from antler and bone were found alongside ceramics and lithics (Andersen 1994-1995). Numerous wooden artefacts including hazel wood sticks and paddle blades (Figure 2.32) were found in the former lake margin. The former have been interpreted as the remains of degraded fishing structures for the capture of freshwater species of fish that were found in the assemblage (Enghoff 1994-1995). Despite the distance from the Kattegat in the region of 15-20 km, the remains of marine organisms, including dolphin, fish, European oysters, and whale were recovered (Rowley-Conwy 1994-1995). These data imply a degree of contact with the coastline. In addition, since the marine fish remains were scattered over a distance of ca. 35 m they may represent several depositional episodes (Andersen 1994-1995; Enghoff 1994-1995). The site has been interpreted as either a seasonal hunting camp that was occupied throughout the winter/spring (Rowley-Conwy 1994-1995) or a permanent inland base camp with intensified hunting that was undertaken seasonally during the late summer/early autumn (Carter 2006). Based on a series of AMS radiocarbon dates the settlement covered the entire time span of the EBK as well as the beginning of the TRB, ca. 5400-3550 cal BC. The Mesolithic-Neolithic transition has been identified as falling at ca. 3940-3820 cal BC

(Andersen 1994-1995; Enghoff 2011).

Figure 2.32: One of the paddle blades recovered from Ringkloster.

2.4.5.7. Salpetermosen

Salpetermosen is a complex of two settlements, Salpetermosen I and Teglgaardslund/Salpetermosen II, which are situated in northeast Zealand. More than 50 species of birds, fish and mammals have so far been identified in the faunal assemblage. It was excavated intermittently from 1956-1997. Based on one AMS radiocarbon date from a dog bone, the assemblage is dated to the EBK, ca. 4600-4200 cal BC. Analysis of the settlement phases and seasonality indicators have demonstrated to the author that the site was used primarily for the exploitation of red deer, from March until June (Kramer 2001).

An isolated find spot situated in a boggy area between two streams was also identified at the locality. During the TRB two lakes are more than likely to have been present. In total,

one complete vessel, sherds from a funnel beaker and funnel bowl, two thin butted polished flint axes, a thin-butted green axe, faunal remains and a slate axe were found at the site. These were recovered from varying depths within or immediately outside a construction area, which was represented by vertical poles and a whole thick layer of brushwood. This construction would have made accessibility easier for humans along the margin of the former lake. The placing of the vessels, axes and animal remains was intentional, and took place during the early and middle Neolithic. Nearby, the remains of two oxen, fish traps, a striking weapon made from deer antler were also recovered. In the southern basin of the present day peat bog a dugout canoe and a human skeleton with a bronze dagger were found. Based on one AMS radiocarbon date on the interior food crust from one of the vessels, the cache deposited on the construction is dated to the TRB, ca. 3350-2950 cal BC (Craig *et al*. 2011; Koch 1998).

2.4.5.8. Stenø

Stenø is an inland settlement that is located on the shore of a former lake in the Åmose, Zealand. The site has only recently been excavated, and is represented by a habitation area that is located on peat adjacent to the lake as well as a refuse zone in the margins of the lakeshore. In the refuse zone numerous artefacts and organic materials were recovered including ceramics, charcoal, fish and mammal remains, lithics, mollusc shells and uncharred plant remains, for instance hazelnuts. In general, the ceramics were composed of fragmentary sherds, and have been dated from the EBK to the TRB (Saul 2011). A fragment deriving from an EBK lamp represented the earliest ceramics at the site, and there are three sherds consistent with the Type 0 'hybrid' vessels that have been dated to ca. 3950 cal BC (Koch 1998; Saul 2011). Based on one AMS radiocarbon date from a terrestrial mammal bone, the assemblage is dated from ca. 4250-3950 cal BC (Saul *et al*. 2013). However, it not yet clear whether this date is representative of the whole assemblage (Saul *et al*. 2013). Regardless, Stenø is contemporaneous with the earliest evidence of domesticates in the region (Craig *et al*. 2011; Saul 2011; Saul *et al*. 2013).

2.4.5.9. Ulkestrup Lyng

Ulkestrup Lyng is located in the Åmose on the island of Zealand. The site is presently a

peat bog. In total, an axe shaft made from birch, two complete vessels, and five sherds deriving from funnel beakers were recovered during the digging of drainage ditches. One of the intact vessels and one sherd were found ca. 10 m apart near to a human skeleton. Approximately 10 m to the north, the axe shaft was recovered. The other artefacts were recovered ca. 30 m to the north from within another ditch. All vessels were found in a transitional layer between peat and gyttia with small freshwater molluscs. They had been intentionally deposited into the former lake. The artefacts were gifted to the National Museum in 1949. Based on one AMS radiocarbon date on the interior food crust from one of the vessels, the cache is dated to the TRB, ca. 3300-2650 cal BC (Craig *et al*. 2011; Koch 1998).

2.4.5.10. Åkonge

Åkonge is one of a number of inland settlements that are located on the shore of the former lake Åmose in northern Zealand. The site encompasses a settlement area, a freshwater shell midden that was primarily composed of *Anodonta* mussels and a refuse zone. It was excavated by the Danish National Museum in collaboration with the National Agency for the Protection of Nature, Monuments and Sites from 1984-1985. The site is also a former lake, and situated ca. 25 km from the coastline. The anthropogenic material is represented by ceramics, including EBK and TRB vessels, which were found alongside the remains of domesticates. Noteworthy are the remains of two hybrid vessels as well as an EBK blubber lamp. The faunal remains were deposited into what were once the shallow waters in front of the site. In addition, bark flooring or mats composed of linearly arranged wooden beams associated with bark were recovered (Enghoff 1994, 1995, 2011; Fischer 2002; Saul 2011). While the majority of the assemblage is awaiting publication, the faunal and fish components have been summarised (Enghoff 1994, 1995; Gotfredsen 1998). The site has been interpreted as a seasonal fishing and hunting locality that was occupied for a short time frame. A series of AMS radiocarbon dates indicate that the site was in use from ca. 4250-3670 cal BC (Enghoff 1994, 1995, 2011; Fischer 2002; Gotfredsen 1998; Saul 2011).

2.4.5.11. Øgårde Kar A

Øgårde Kar A is one of a number of sites forming the Øgårde complex in the Store Åmose,

northern Zealand. The site is presently a peat bog and represented by a number of artefacts that were intentionally deposited into the former lake. Based on one AMS radiocarbon date on the interior food crust from one vessel, the cache is dated to the TRB, ca. 3950-3650 cal BC (Craig *et al*. 2011; Koch 1998).

2.5. Summary

In order to complement the data derived from the Havnø kitchen midden, and place the site into the wider context, 32 other Danish archaeological sites were integrated in the present study. For comparison with the Havnø kitchen midden, the primary focus of the sampling strategy was to include materials dating to the EBK and TRB cultures. However, in order to examine regional variability, sites that were similarly located but younger, for instance Kalvø, were included. Moreover, sites located on the islands of Funen and Zealand were integrated in order to allow a comparison to be made between the east and west of the country. While the majority of the samples were analysed by the author, for instance the fish remains from four kitchen middens (Chapter 6), some samples have been re-examined, for example the European oysters from Bjørnsholm (Chapter 4). In addition, others have been made available, for instance the single compound specific isotope data derived from the ceramic vessels recovered at the lakeshore settlement at Ringkloster (Chapter 5).

3. Stable isotopes and radiocarbon dating

3.1. Introduction

In archaeological science there are a number of light stable isotopes that are routinely analysed, including, carbon (C), hydrogen (H), nitrogen (N), oxygen (O) and sulphur (S). However, the biomolecular analyses of faunal, fish and human bone collagen, in particular measurements of the light stable carbon isotopes of ^{12}C to ^{13}C, and those of nitrogen ^{14}N to ^{15}N, are almost exclusively utilised for palaeodietary reconstruction (Pollard and Heron 2008).

This chapter commences with the definition, terminology and notation of stable isotopes before a history of isotope research. This will be followed by an outline of the methods and sampling procedures that have been developed for the isotopic analysis of human and faunal bone collagen in order to examine both palaeodiet and the palaeoenviroment. The stable isotope analyses of carbon, nitrogen and sulphur from human and faunal bone collagen from the Havnø kitchen midden will then be presented. This will be followed by the application of FRUITS, a Bayesian mixing model to obtain a more accurate reconstruction of the consumers' diets, and AMS radiocarbon dating to confirm their relative age and contextualize the stable isotope data.

For the present study human remains were selected for analysis from the Havnø kitchen midden. There were two main objectives:

- To determine how many individuals were present in the assemblage.
- To examine the character, extent and intensity of dietary changes (if any) across the Mesolithic-Neolithic transition.

In order to improve the accuracy of the human dietary information, 20 fish remains were selected for analysis in this study to:

- To characterize individual species of fish to freshwater, brackish and marine environments.
- Reconstruct trophic level hierarchy.
- Establish any migration patterns.
- Determine intra-species variation within and between fish populations differing temporally.

For inter-site comparison, human remains from the Holmegård kitchen midden dating to the EBK were sampled. In addition, bird remains from the stratified kitchen midden at Thygeslund were selected for analysis. Furthermore, carbon and nitrogen stable isotope analysis that had been previously undertaken on human remains recovered from 54 EBK and TRB sites have been examined. Thus, the Havnø data can be interpreted within the context of 55 Danish archaeological sites.

3.2. Definition, terminology and notation of stable isotopes

The application of carbon and nitrogen stable isotope analysis of archaeological bone collagen was established in 1977, and has become an important technique for understanding past human behaviour, for instance the diet, status, and mobility of an individual (Vogel and van der Merwe 1977). It is considered important for three reasons: (1) the foods consumed as opposed to those discarded can be examined, (2) the diet of an individual, albeit long term, can be analysed, which can be used to discriminate between different individuals, and (3) the relative contribution of different sources of protein can be quantified (Lee-Thorp 2008; Pollard and Heron 2008).

The founding principle of isotopic dietary reconstruction is that elements 'differ slightly in their nuclear mass as a result of differences in the number of neutrons, leading to small but significant differences in their thermodynamic and kinetic properties. Molecules containing the higher-mass, rarer isotope tend to accumulate in the thermodynamically most stable component of a system-for instance, in the liquid rather than gaseous phase-or are slower to react in mass-sensitive kinetic reactions' (Lee-Thorp 2008, 927). In short, it is possible to distinguish between a diet rich in marine protein from one composed of terrestrial mammal

protein, and the consumption of maize can be distinguished from other cereals and vegetables because of differences in the carbon isotope fractionations during photosynthesis (Peters *et al*. 2007). Despite the two-stage fractionation process during photosynthesis, which occurs in both marine and terrestrial environments, marine environments differ due to the incorporation of dissolved bicarbonate at the onset of photosynthesis that is enriched in ^{13}C compared to the atmosphere. This ultimately leads to more positive $\delta^{13}C$ values for the marine organisms. Since it is possible to confuse a diet based on marine protein with one rich in the consumption of maize, the application of nitrogen stable isotopes, ^{14}N to ^{15}N, provides greater precision as it is a reflection of the isotope shifts that occur along a food chain (Pollard and Heron 2008). By plotting the values of $\delta^{13}C$ against $\delta^{15}N$, the relative protein contribution to the overall diet can be estimated. An example of a generalised isotopic trophic level bi-plot for $\delta^{13}C$ and $\delta^{15}N$ values from marine and terrestrial resources is provided in Figure 3.1.

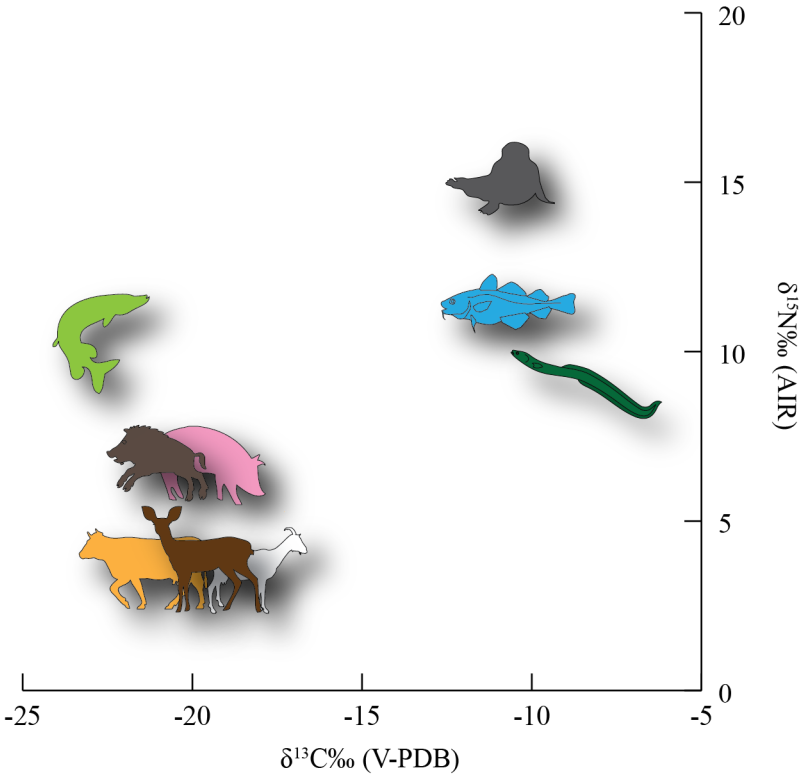


Figure 3.1: Typical stable carbon and nitrogen isotope values for terrestrial (C3) and marine mammals, as well as freshwater and marine fish. Note that consumers will have typically have $\delta^{15}N$ values that are +3‰ higher than their prey.

3.2.1. Dietary reconstruction from bone

Stable isotopes are preserved in all biological materials that survive in the archaeological

record, including bioapatite, keratin, lipids as well as tooth dentine and enamel. Although the long-term stability of collagen has been questioned (Macko *et al*. 1999), subsequent research has demonstrated that while it breaks down more quickly when compared to apatite, the stable isotopes remain intact even when a large proportion of the original collagen molecules have receded (Collins *et al*. 2002). Similarly, bone apatite has been shown to be diagenetically altered that influences the stable isotopes, whereas tooth enamel remains relatively intact (Lee-Thorp 2008). It is for these reasons why bone collagen is the most commonly analysed material since it is often better preserved and more integral. Moreover, it is possible to characterise well-preserved collagen using quality controls that cannot be applied to apatite.

Stable isotope values are designated by the delta notation (δ), and expressed in parts per thousand or per mil (‰) relative to an international standard. For carbon the standard is a marine limestone called Peedee belemnite (V-PDB); for nitrogen Ambient Inhalable Reservoir (AIR); and for sulphur it is the Canyon Diablo Triolite (V-CDT). Given the complex nature of biological systems, the introduction of isotopic fractionation can ultimately distort our interpretation of the dietary information. Since the effects of metabolism on fractionation are not fully understood, there is an emphasis towards the heavier or lighter isotope ratio (Pollard and Heron 2008).

3.2.2. Protein routing

Collagen is the main structural protein found in animal connective tissue. It is the organic component of bone comprising around 20% of its dry weight (Pollard and Heron 2008). Collagen is constantly remodelled throughout the lifetime of an individual with turnover rates ranging from approximately five to thirty years, although this is subjective to the age and skeletal element (Hedges *et al*. 2007). However, it is generally accepted that bone collagen provides information on the sources of dietary protein over the last 10 or so years prior to death (Schulting and Richards 2001). But it is unlikely to represent an average of long-term subsistence on species where little is known about their protein turnover rates, for instance fish. Ambrose and Norr (1993) and Tieszen and Fagre (1993) have shown that while collagen primarily reflects the carbon isotopes of dietary protein, biological

carbonate, that is bone apatite, is indicative of total diet that incorporates carbohydrates, fats, lipids and proteins.

Since nitrogen is the only source of protein in the diet, the $\delta^{15}N$ values derived from bone collagen are therefore a reflection of the protein component in the diet (Chisholm *et al*. 1982; Hedges *et al*. 2006). In comparison, carbon is derived from all dietary fractions, including essential and non-essential amino acids that contribute ca. 20% of the carbon in the diet (Jim *et al*. 2004; Howland *et al*. 2003). This contribution therefore represents the minimum proportion of collagen that is solely derived from dietary protein (Jim *et al*. 2004). On the other hand, non-essential amino acids comprise the majority, ca. 78%, of the carbon in the collagen. Although it was originally understood that this value was derived from non-essential amino acids that were synthesised from all fractions of the diet (including carbohydrates, proteins and lipids), controlled feeding experiments have indicated that they are derived from the protein in the diet, and thus not a reflection of whole diet (Ambrose and Norr 1993; Jim *et al*. 2004; Tieszen and Fagre 1993). In order to elucidate the contribution of dietary carbon to the whole bone collagen $\delta^{13}C$ values, further experimentation is required (Hedges 2004).

3.2.3. Carbon, nitrogen, and sulphur stable isotopes

3.2.3.1. Carbon ($\delta^{13}C$)

Carbon ($\delta^{13}C$) is the main element used in palaeodietary reconstruction, and represents the ratio of ^{13}C to ^{12}C in a sample (Schulting and Richards 2001). While the majority of terrestrial flora employ Calvin photosynthesis (C_3), there are some, notably those from subtropical and tropical environments that have adapted to increased light, higher temperatures and limited water availability, and thus employ Hatch-Slack photosynthesis (C_4). As a reflection of this difference in fractionation, C_4 floras have $\delta^{13}C$ values from -16.0‰ to -12.0‰, with a mean of -12.5‰ (Ehleringer and Monson 1993). Similarly, marine C_3 floras differ when compared with those derived from terrestrial biotopes due to the incorporation of dissolved bicarbonate. Consequently their $\delta^{13}C$ values are enriched in ^{13}C compared to the atmospheric carbon dioxide across the air to water interface (Peters *et*

al. 2007). Given the similar $\delta^{13}C$ values of C_4 floras and marine organisms the situation can become convoluted during data interpretation especially when an individual consumed both or either resources (Bender 1971). Fortunately, the majority of C_4 floras, for instance maize (*Zea mays*), millet, sorghum, subtropical grasses and sugar cane (*Saccharum* sp.) are not native to central and northern Europe, as well as the Baltic regions. Since they are a relatively recent domesticate this complication can largely be ignored during the stable isotope analysis of pre-Neolithic human and faunal bone collagen (Pollard and Heron 2008; Tauber 1981).

Despite differences for the estimated endpoint corresponding to a 100% marine protein derived diet, -16.0‰ (Pollard and Heron 2008), -12.0‰ (Ehleringer and Monson 1993), and -10.1‰ (Arneborg *et al*. 1999), in the present study the latter will be adhered to, whereas the estimated endpoint of -21.7‰ corresponds to a diet reflecting 100% terrestrial protein.

Given that floras are at the base of the food chain, the isotope ratios within animal body tissues are enriched as they move through consumers, and up the trophic level hierarchy (Tykot 2004). The trophic level enrichment of bone collagen in carbon along the food chain is 1-2‰ (Pollard and Heron 2008). Differences in the diet and position of a consumer in the food chain also affect the isotopic ratios in bone collagen, and can be broadly used to determine what has been consumed, and from where they are derived from.

In addition, bone collagen isotopic ratios can vary depending upon the restricted nature of the environment in which the consumer resides. This is a consequence of the differential recycling of carbon dioxide that is depleted in ^{13}C, which has been observed in various forest strata. Thus, the foliage near to the forest floor in notably closed and dark biotopes have the most depleted $\delta^{13}C$ values (Ambrose and DeNiro 1986). This has been termed the canopy effect (Bonafini *et al*. 2013; Noe-Nygaard 1995). In this manner, a general impression of the environment in which herbivorous mammals resided can be examined through stable isotope analysis since herbivores residing in more open environments, for instance grassland will exhibit more enriched $\delta^{13}C$ values when compared with their dark-

forest counterparts (Ambrose and DeNiro 1986; Bonafini *et al*. 2013; Noe-Nygaard 1995; Noe-Nygaard *et al*. 2005).

3.2.3.2. Nitrogen ($\delta^{15}N$)

Nitrogen ($\delta^{15}N$) is the second most commonly utilised element, which represents the ratio of ^{15}N to ^{14}N in a sample (Schulting and Richards 2001). Since nitrogen ratios are derived from protein, the $\delta^{15}N$ values obtained from bone collagen reflect the sources of dietary protein and are indicative of trophic level. In principle $\delta^{15}N$ values discriminate between a terrestrial biome, and differential access to marine resources. In general, birds as well as domesticated and wild terrestrial mammals have a mean $\delta^{15}N$ value of +5.9‰, while marine mammals have a mean $\delta^{15}N$ value of +15.6‰ (Schoeninger *et al*. 1983). This difference is a consequence of the nitrogen fractionation in marine ecosystems that results in longer food chains than their freshwater or terrestrial counterparts (Pollard and Heron 2008). In a similar manner to carbon isotopes, consumer enrichment occurs. On the whole it is estimated that the isotopic shift that occurs along the food chain is between +2.0‰ and +5.0‰ per trophic level (Bocherens and Drucker 2003; Drucker and Bocherens 2004; Hedges and Reynard 2007). Moreover, the process of fractionation equally applies to those individuals that breastfed since they are in essence preying on their mothers. As a consequence their $\delta^{15}N$ values are generally one trophic level further along the food chain (Fornander *et al*. 2008).

In cases whereby an individual exhibited a mixed diet comprising of both marine and terrestrial derived protein, interpretation of the $\delta^{15}N$ values can be problematic, and are subjective to the observed two end points (Schulting and Richards 2001). For instance, if the $\delta^{13}C$ value were indicative of marine derived protein then one would expect an elevated $\delta^{15}N$ value. However, when a combined diet is represented by the incorporation of marine and terrestrial protein, the $\delta^{15}N$ value may depict one of the following: (1) protein derived from resources lower down in the trophic level hierarchy, for example C_4 flora, (2) protein derived from resources higher up in the marine trophic level hierarchy, for example mammals, or (3) a combination of the two. When complication arises, additional lines of enquiry should be taken into consideration, for example contemporaneous faunal remains

(Schulting and Richards 2001).

3.2.3.3. Sulphur ($\delta^{34}S$)

Sulphur ($\delta^{34}S$) representing the ratio of ^{34}S to ^{32}S in a sample is an element that has only recently been applied to address questions of archaeological importance (Lee-Thorp 2008; Smits and Plict 2009). Although sulphur stable isotope analysis has been undertaken since the 1980s (Krouse *et al*. 1987), it has not been commonly performed on archaeological material due to analytical cost, technical difficulties, as well as the quantity of bone that was required prior to improvements in Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS) (Barnes *et al*. 2007; Hansen *et al*. 2009; Lee-Thorp 2008).

In comparison with carbon and nitrogen stable isotopes, sulphur is geographically specific since it primarily reflects the local underground geological sulphate. Thus, it has the potential to discriminate between the consumption of different resources and establish the provenance of animals (Katzenburg and Krouse 1989; Krouse and Herbert 1988). In addition, sulphur has the potential to identify immigrants within a population (Nehlich and Richards 2009). However, modern anthropogenic pollution can also effect the natural sulphur isotope composition of bone collagen (Faure and Mensing 2005; Nehlich *et al*. 2010). While $\delta^{34}S$ values are influenced by a number of factors including altitude, distance from the sea and precipitation (Budd *et al*. 2004), not all of the potential sources of variation have been identified.

Recently it has been suggested that ca. 10 mg of mammal bone collagen is required for a reliable isotope value. Since fish have higher quantities of sulphur in their bone collagen, which may be partly explained by methionine that is an essential amino acid for fish (Cantoni 1975), and the burial environment (Nehlich and Richards 2009), ca. 6 mg is deemed necessary (Nehlich and Richards 2009). In a similar manner, sulphur stable isotope analysis of archaeological bone collagen (Nehlich *et al*. 2013; Richards *et al*. 2001), and hair (Macko *et al*. 1999) has been undertaken for dietary and environmental reconstruction. It has been a useful adjunct to carbon and nitrogen stable isotope analysis (Smits and Plict 2009). Moreover, sulphur stable isotope analysis been used to distinguish the contribution

of different producers within aquatic food webs, for instance estuarine, freshwater, marine and terrestrial biomes (Krouse and Herbert 1988; Leakey *et al*. 2008; Privat *et al*. 2007).

Birds and terrestrial mammals routinely have $\delta^{34}S$ values ranging from -20.0‰ to +14.0‰. Despite the degree of variability, they are generally more depleted when compared to the more uniform $\delta^{34}S$ values derived from marine organisms (Nehlich and Richards 2009). Similarly, local baselines tend to exhibit a restricted range (Nehlich *et al*. 2013). In comparison, marine mammals including seals and whales from open oceanic waters as well as mammals residing in coastal areas or whose diet was largely derived from aquatic protein typically have $\delta^{34}S$ values ranging from +16.0‰ to +20.0‰ (Krouse and Herbert 1988; Nehlich and Richards 2009; Nehlich *et al*. 2013; Peterson and Fry 1987; Rees *et al*. 1978).

It has been suggested that the threshold of +15.0‰ distinguishes between marine and estuarine environments (Fry 1988). In light of this $\delta^{34}S$ value, and recent research (Nehlich *et al*. 2013), several of the aforementioned ranges have been re-defined to the following: -20.0‰ to +14.0‰ for estuarine and freshwater birds, fish and terrestrial mammals; specifically -5.0‰ to +10.0‰ for freshwater and riverine fish (despite modern freshwater fish exhibiting $\delta^{34}S$ values from -20.0‰ to +22.0‰); and +10.0‰ to +15.0‰ for individuals whose habitats are largely influenced by freshwater inputs though may have originated from close to the coast or an estuarine environment.

While sulphur stable isotope analysis can differentiate between different biome-based diets and locations of residency, it can also be used to ascertain potential contamination. Generally this is in the form of marine sulphates within terrestrial food chains particularly at coastal or islet localities (Craig *et al*. 2006). This is based, in part, on sea spray and coastal precipitation (McArdle *et al*. 1998). Although they can have implications during interpretation (Lee-Thorp 2008), it must be borne in mind that an individual exhibiting a marine signature does not necessarily reflect the consumption of marine derived protein but rather the consumers' proximity to the sea (Fornander *et al*. 2008).

Unlike the isotopic ratios of carbon and nitrogen there appears to be little fractionation in sulphur within an ascending food chain (Richards *et al*. 2001). Some have reported that consumer enrichment is as little as ca. -1‰ or +2‰ (Linderholm *et al*. 2014; Nehlich *et al*. 2009; Privat *et al*. 2007). Given the broad range of $\delta^{34}S$ values (-20.0‰ to +20.0‰) within marine and terrestrial ecosystems this value can largely be ignored (Richards *et al*. 2001).

3.2.4. Food Reconstruction Using Isotopic Transferred Signals

While dietary reconstruction by stable isotope analysis aims to provide an estimate of the relative proportions of potential food groups, several sources of uncertainty are often neglected during data interpretation (Fernandes *et al*. 2014). Carbon stable isotope values obtained on bone collagen have proven useful when quantifying the general contribution of marine and terrestrial resources (Schoeninger *et al*. 1983), however the differential dietary routing of food fractions including macronutrients (energy, including carbohydrates and lipids, as well as protein) are largely ignored (Fernandes *et al*. 2012). Within ecological studies research using biochemical methods and Bayesian statistics are routinely undertaken to determine the proportion of mixed trophy (Phillips and Gregg 2003). They are scarcely applied to archaeologically derived data, and would be usefully applied to handle the diverse sources of uncertainty (Fernandes *et al*. 2014). Food Reconstruction Using Isotopic Transferred Signals (FRUITS) is a Bayesian mixing model that has recently been developed for dietary reconstruction using stable isotope data. Unlike other isotope mixing models such as Stable Isotope Analysis in R (SIAR), FRUITS has the capability to account for the macronutrients towards a dietary proxy signal measured in the consumer (Fernandes *et al*. 2014). In order to accurately predict intake estimates of the food resources consumed by the human remains recovered from the Havnø kitchen midden, FRUITS was applied in this study.

3.2.5. Accelerator Mass Spectrometry (AMS) radiocarbon dating

An essential adjunct to dietary interpretations is AMS radiocarbon dating. It is the most commonly used method to establish absolute chronologies, and is based on the radioactive isotope of carbon (^{14}C). While human remains are often utilised, it has recently been demonstrated that the dates obtained may be unreliable. This is because humans obtain their

carbon via the resources consumed. Consequently the ^{14}C concentration in their bone collagen reflects the ^{14}C concentration of the resources eaten. Thus, if some of the resources consumed had different ^{14}C concentrations when compared with the atmosphere, that is the reservoir age, equally the human will exhibit this offset. In certain circumstances they will appear to be too old particularly when various contributions of aquatic derived protein had been consumed. This is because it takes approximately 400 years for the current atmospheric CO_2 to equilibrate with the water column, since deep-water carbon is already undergoing radioactive decay prior to being taken up by marine organisms. This ^{14}C age offset between the atmosphere and aquatic reservoirs are termed freshwater (FRE) and marine reservoir effects (MRE) depending upon the environment (Ascough *et al*. 2004, 2010; Fernandes *et al*. 2013). Given the variable MREs in Danish fjord systems (Heier-Nielsen *et al*. 1995), and the importance of the transition to the Neolithic, five human remains from the kitchen midden were AMS radiocarbon dated in this study to contextualize the stable isotope data.

3.3. History of research and previous studies on Danish transitional material

From 1981 to the present, isotopic studies of diet have widely been undertaken on human remains dating to the Mesolithic and Neolithic of Europe in order to better our understanding of cultural changes that have been observed archaeologically (Tauber 1981; Fischer *et al*. 2007). Moreover the stable isotope analyses of human remains have also demonstrated potential mobility patterns throughout Europe (Fontanals-Coll *et al*. 2014). The earlier studies (for example Lubell *et al*. 1994; Papathanasiou 2003; Richards and Mellars 1998; Richards *et al*. 2003a; Schulting and Richards 2001; Tauber 1981) are, however, fraught with issues, notably the lack of analyses undertaken on contemporaneous faunal bone collagen. This is particularly pertinent since local baselines differ. Thus, with increasing regularity the analyses of domesticated and wild (marine and terrestrial) mammal remains have been undertaken in order to primarily provide a palaeoecological baseline for the interpretation of the human bone derived data, but also to establish the nitrogen enrichment from prey to consumer as well as certain aspects of the animals' habitat use and life histories (Noe-Nygaard 1995; Noe-Nygaard *et al*. 2005; Noe-Nygaard

and Hede 2006; Price and Noe-Nygaard 2009). In addition, the analysis of fish bone collagen has discriminated between freshwater, brackish (estuarine) and marine carbon pools, which have challenged previous interpretations (Enghoff 1986) concerning aquatic resource exploitation strategies (Fischer *et al*. 2007; Robson *et al*. 2012, 2015). While the study by Fischer *et al*. (2007) highlighted a strong reliance on aquatic protein, numerous questions remained unanswered, for instance how overexploitation and/or environmental fluctuations including temperature, salinity, food supply, habitat loss, pollution as well as predator attacks may have affected human diet during these periods. In the study by Robson *et al*. (2012) it was demonstrated that European eel recovered from coastal Mesolithic and Neolithic sites in northern Germany and Denmark had carbon isotope values consistent with marine residency. Since European eel have been considered as one of the most important species of fish during the Atlantic and Sub-Boreal chronozones in Denmark (Enghoff 2011; Enghoff *et al*. 2007), in light of the isotope data it was suggested the marine isotope values observed from contemporaneous human remains in the region (Fischer *et al*. 2007) are consistent with the consumption of significant quantities of marine protein (Robson *et al*. 2012, 2015).

In comparison with the majority of other European regions, Denmark has not been hampered by small sample sizes of Mesolithic and early Neolithic human remains (Schulting 2011). Consequently there is a large corpus of carbon and nitrogen stable isotope data from human as well as faunal bone collagen available (Fischer *et al*. 2007; Schulting 2010). However, since the majority of human remains dating to the early Neolithic are derived from inland localities, for example isolated bog finds and passage graves (Fischer *et al*. 2007) it has been difficult to assess temporal change across the Mesolithic-Neolithic transition particularly for coastal localities, including kitchen middens. In general there are few data available on individuals recovered from the same site as well as from sites in close proximity to one another. Thus, it has been difficult to identify and compare contemporaneous groups. In addition, issues have arisen due to the shifting land-sea relationship in southern Scandinavia, which has more than likely affected the species spectra throughout the entire period (Schulting 2010). Moreover, as a result of the fluctuating sea levels the early Mesolithic Maglemose human individuals are largely

restricted to inland localities. It is therefore not surprising that the stable isotope data contrast starkly with those obtained from EBK and early/middle Neolithic human individuals (Fischer *et al*. 2007a; Schulting 2010, 2011).

In general, previous research has demonstrated that the EBK human diet was principally composed of resources of marine protein, whereas the subsequent TRB peoples appear to have turned their backs on the sea, adopting terrestrial products to the exclusion of aquatic resources (Schulting and Richards 2001; Richards *et al*. 2003b). This assumption however has not always been borne out of the archaeological (Milner *et al*. 2004, 2006; Pedersen 2013), and isotopic evidence (Craig *et al*. 2007, 2011; Lidén *et al*. 2004).

While the question on the nature and speed of the transition to the Neolithic is an important one it is fraught with complications, including AMS radiocarbon dates coupled with the reliance on aquatic derived protein and the spatially and dependent reservoir effects (Heier-Nielsen *et al*. 1995; Philippsen 2013). Consequently, there has often been an over assignment of individuals on either side of the transitional period, ca. 4000 cal BC when diagnostic material culture is absent (Brinch Petersen and Meiklejohn 2009; Schulting 2011). These data are plotted in Figure 3.2, listed in Table 3.1, and will be discussed below.

In 1975 during the excavations at the Vængesø II kitchen midden a double burial (Figure 3.3) was recovered (Andersen *et al*. 1986). While the two individuals, represented by a male and female, had been previously AMS radiocarbon dated (Andersen *et al*. 1986), it has only been recently demonstrated that both dates were uncalibrated (Brinch Petersen and Meiklejohn 2009). When corrected for the MRE the double burial appears to date too close to the so-called Tauber Line, ca. 3950 cal BC (Brinch Petersen and Meiklejohn 2009) for assignment to cultural epoch. Based, in part, on the re-extraction of bone collagen from the two individuals (Fischer *et al*. 2007) it can clearly be seen that they had had a long-term diet that had principally been composed of marine derive protein. However, when corrected by the author for the MRE using the Marine13 curve (Reimer *et al*. 2009), and by applying a marine reservoir correction based on local marine mollusc data (see section 3.6.5. Calibration of the AMS radiocarbon dates), the individual belonged to the TRB, which

clouds the temporal boundary at the onset of the Neolithic.

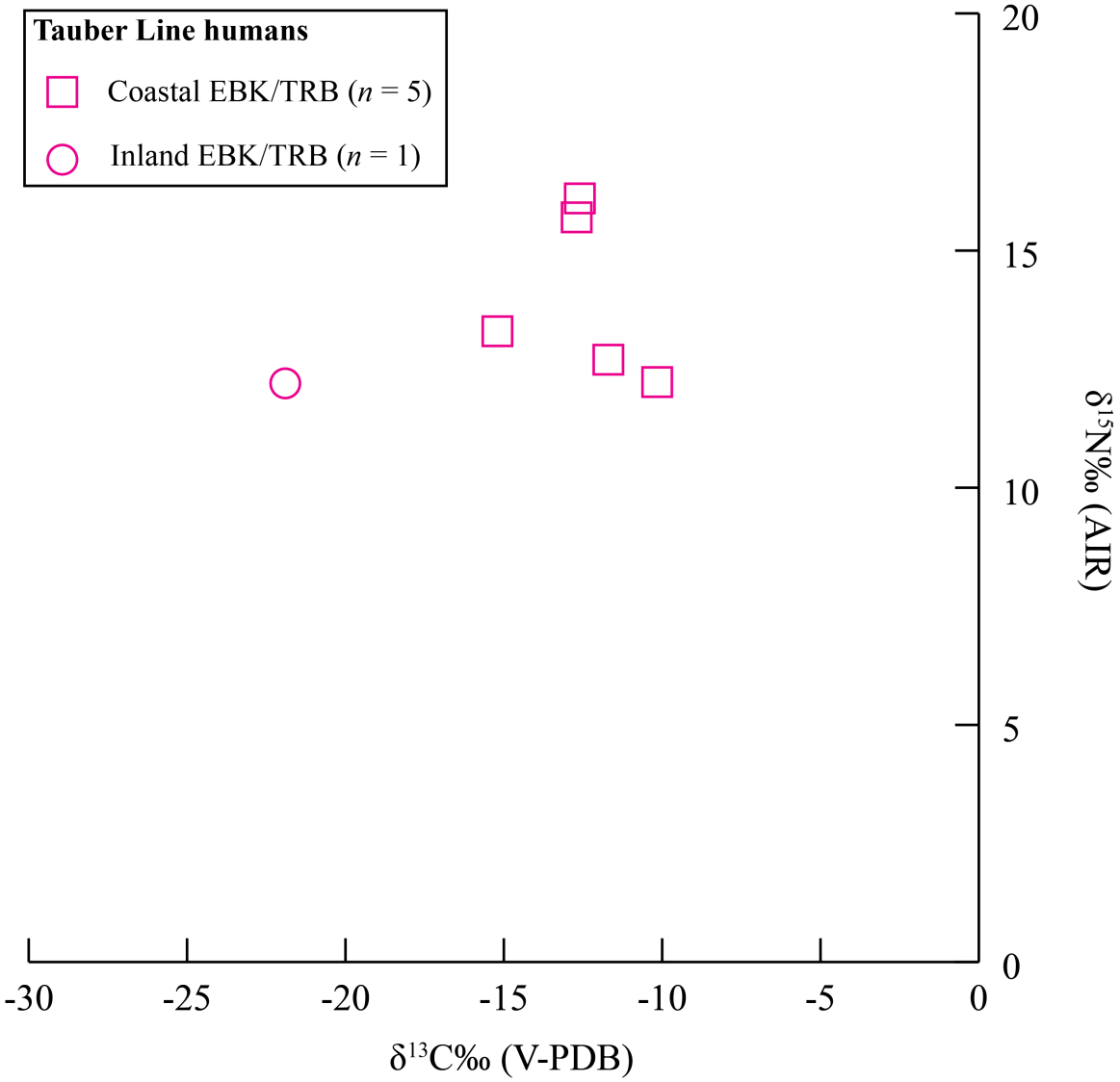


Figure 3.2: Carbon and nitrogen isotope data obtained from human bone collagen from five Danish archaeological sites that have been dated to either the EBK or TRB (reproduced from Fischer et al. 2007).

Similarly, the AMS radiocarbon date derived from an inhumation buried at the Melby site (Lund Hansen *et al*. 1972) was not corrected. The recent carbon and nitrogen stable isotope analysis and AMS radiocarbon dating has for the time being quelled previous discussions. This individual has now been dated to the EBK and it can be seen that it had a long-term diet consistent with marine derived protein (Brinch Petersen and Meiklejohn 2009).

Site name	Lab code	Skeletal element	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio	C14 age BP	Calibrated age at ± 1 sigma
Ertebølle	K-4933/AAR-8555/E. 2842	Tibia dxt., >25 y	-15.2	13.3	3.2	5790 ± 30	4470-4230
Melby	AAR-8551/AS 18/73	Femur sin., adult > 35 y	-10.7	13.3	3.2	6280 ± 35	4810-4670
Rødhals	AAR-8552	Femur dxt., ~25 y	-11.7	12.7	3.2	5360 ± 50	3870-3700
Tingbjergg ård Vest	AAR-7032/T.v.704, A47874	Femur, adult	-21.9	12.2	3.2	5452 ± 48	4240-4100
Vængesø II	K-3920/BCH198: 45a+b	Femur etc., adult	-12.7	15.7	3.3	5500 ± 70	3950-3500
Vængesø II	K-3921/BCH195: 13+14	Costa, vertebra etc., 20-30 y	-12.6	16.1	3.3	5540 ± 65	3960-3530

Table 3.1: Re-calibrated AMS radiocarbon dates from human remains that had previously fallen on or around the so-called Tauber line (Fischer et al. 2007).

Figure 3.3: Photograph of the double burial at the Vængesø II kitchen midden in 1975 (courtesy of Søren H. Andersen).

In 1895 an inhumation burial containing an adult male (Figure 3.4) was recovered at the eponymous Ertebølle kitchen midden (Andersen and Johansen 1986; Madsen *et al*. 1900; Tauber 1993). Likewise the original AMS radiocarbon date was not corrected and has been of interest given the importance of the kitchen midden, and assumption that the entire midden sequence is of EBK date (Andersen and Johansen 1986). In direct association with the male, lithics typologically dated to the EBK have been argued for (Albrethsen and Brinch Petersen 1976), however it has only recently demonstrated that the male is dated to the EBK and had a long-term diet consistent with marine derived protein (Fischer *et al*. 2007).

Figure 3.4: Photograph of the burial at the Ertebølle kitchen midden in 1895 (after Madsen et al. 1900).

In 1956 an adult male was recovered from a presumed atypical EBK kitchen midden at Rødhals on the island of Sejerø (Fischer *et al*. 2004). Despite a lack of evidence in favour of Neolithic occupation at the kitchen midden the individual has been AMS radiocarbon dated three times (Fischer 2002; Fischer *et al*. 2004, 2007). When corrected by the author for the MRE using the Marine13 curve (Reimer *et al*. 2009), and by applying a marine reservoir correction based on local marine mollusc data (see section 3.6.5. Calibration of

the AMS radiocarbon dates), the individual has been dated from ca. 3870-3700 cal BC. While the individual belonged to the TRB, the stable isotope data are consistent with the long-term consumption of marine derived protein. Thus, the situation is rather complicated (Schulting 2011) because it negates the concept for an abrupt dietary shift at the onset of the Neolithic.

Based on these data alone it would appear that there is unequivocal evidence in favour for the continued long-term consumption of marine derived protein after the Mesolithic. Although the data are derived from only the Rødhals and Vængesø II kitchen middens, it is still unclear whether or not previous assumptions for a dietary change were instantaneous or synchronous throughout Denmark (Schulting 2011). Based on these data as well as evidence in favour for marine resource exploitation (Andersen 2000a, 2001, 2004a, 2007, 2008a; Milner *et al*. 2004; Pedersen 2013), it seems likely that the Rødhals Vængesø II individuals persisted with an EBK way of life at a time when contemporaneous and proximal communities were adopting elements of the Neolithic package (Schulting 2011). However it would be unwise at this juncture to state that the community from which the individual may have equally persisted with the long-term consumption of marine derived protein (Schulting 2011). As previously posed (Richards *et al*. 2003a) there is a need for additional stable isotope analysis and AMS radiocarbon dating particularly from transitional sites including the stratified kitchen middens.

Notwithstanding the carbon and nitrogen isotope data available, relatively few studies have considered the sulphur isotopic analysis of archaeological bone collagen (Fornander *et al*. 2008; Hu *et al*. 2009; Jay *et al*. 2013; Leach *et al*. 1996; Linderholm *et al*. 2008, 2014; Macko *et al*. 1999; Nehlich *et al*. 2010, 2012, 2013; Oelze *et al*. 2012; Privat *et al*. 2007; Richards *et al*. 2001; Smits and Plict 2009; Vika 2009), and only one has been undertaken on material derived from the Danish kitchen middens (Craig *et al*. 2006). Undoubtedly future analysis in combination with carbon and nitrogen stable isotope analysis will yield additional and interesting data regarding dietary reconstruction and environmental reconstruction (Nehlich and Richards 2009).

3.4. Stable isotope analysis of faunal and human remains from Havnø

3.4.1. Previous analyses

A carbon and nitrogen stable isotope study of European eel remains from Danish and northern German Mesolithic and Neolithic sites was undertaken by Robson *et al*. (2012). In their study 12 European eel bones from Havnø were sampled. The analysis demonstrated that the European eel recovered from the Havnø kitchen midden had $\delta^{13}C$ values consistent with marine residency prior to capture (Figure 3.5).

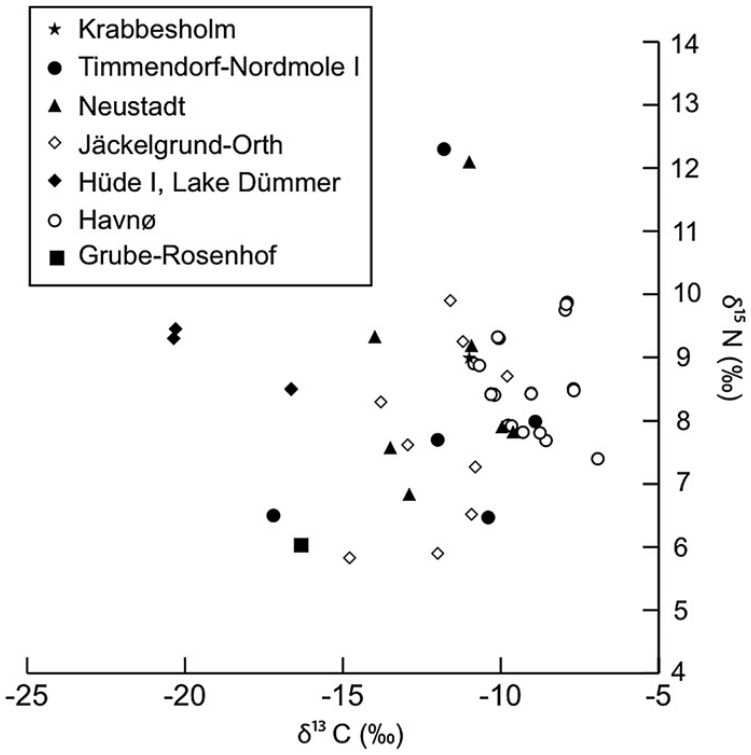


Figure 3.5: Carbon and nitrogen isotope data obtained from eel bone collagen from six Danish and German sites as well as an eel from the Krabbesholm II kitchen midden reproduced from Fischer et al. (2007) (Robson et al. 2012, figure 2).

In addition, a comprehensive carbon and nitrogen stable isotope study had previously been undertaken on 38 faunal remains recovered from the Havnø kitchen midden (Gron 2013a). These data are plotted in Figure 3.6. In his study there were two main objectives: (1) to reconstruct the types of environments in which the wild and early domesticated taxa were feeding, and to determine intra-species variations within and between populations differing temporally in order to ascertain reproducibility over time, and (2) to improve our

understanding of the ecology of the region (Gron 2013a).

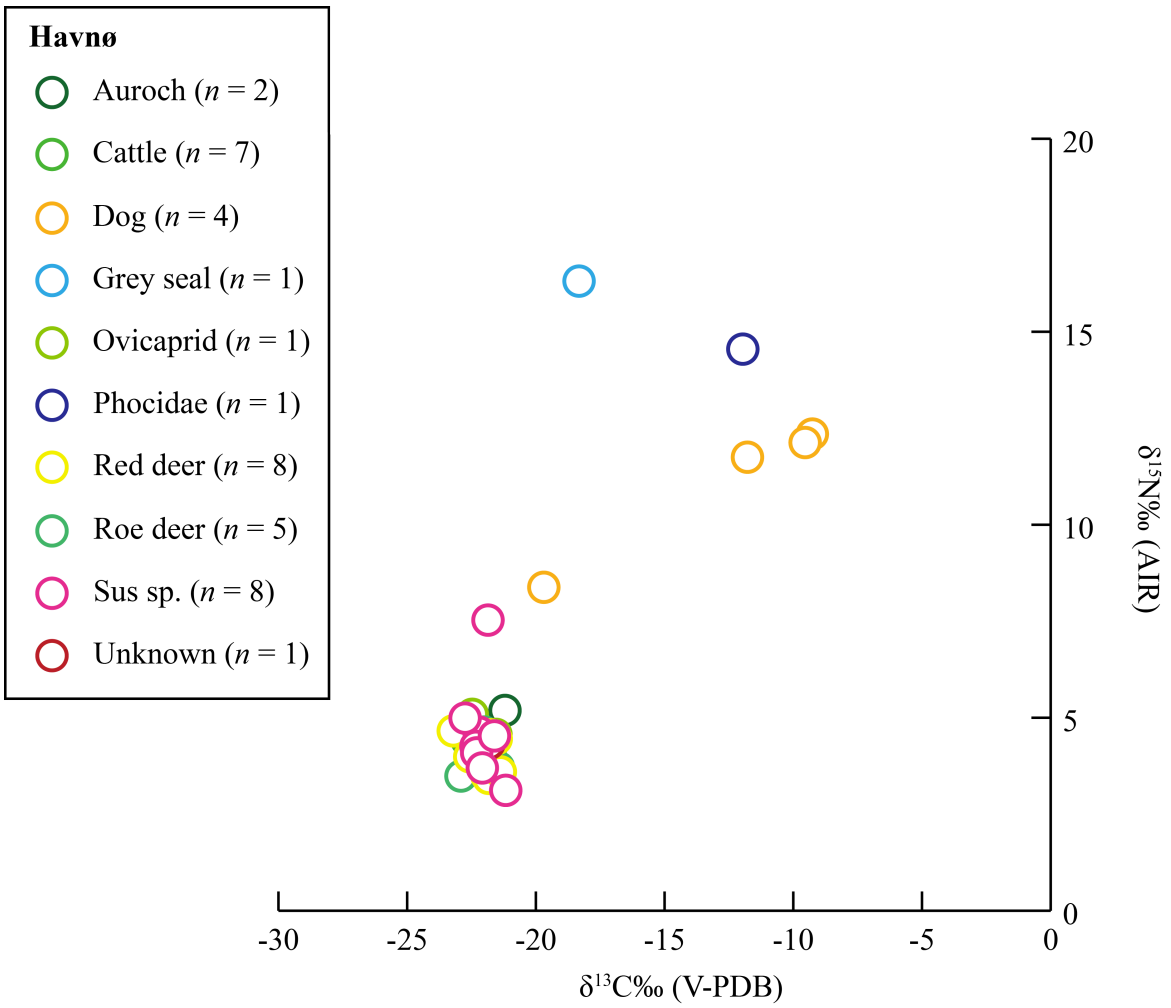


Figure 3.6: Carbon and nitrogen isotope data obtained from mammal bone collagen from the Havnø kitchen midden reproduced from Gron (2013a).

The ten taxa analysed by Gron (2013a) had a broad range in both their $\delta^{13}C$ (-23.2‰ to -9.3‰) and $\delta^{15}N$ (3.1‰ to 14.6‰) values indicating that these taxa were on average feeding at 3.3 trophic levels higher than their producers in these diverse biotopes (difference/3.5). With the exception of the data obtained from dog, the data show a clear difference in the $\delta^{13}C$ and $\delta^{15}N$ values between the terrestrial and marine taxa recovered from Havnø.

The 32 domesticated and wild terrestrial taxa that are represented by auroch, cattle, ovicaprid, red deer, roe deer, and swine exhibited variation in both their $\delta^{13}C$ and $\delta^{15}N$

values. With the exception of one swine, there was no appreciable difference in the $\delta^{13}C$ and $\delta^{15}N$ values between the domesticated and wild taxa. Similarly, there was no significant difference in the $\delta^{13}C$ and $\delta^{15}N$ values between the EBK and TRB, despite the fact that the majority of the samples are derived from the latter culture. One swine possessed a noticeably elevated $\delta^{15}N$ value indicating that it was higher up in the trophic level hierarchy than the other taxa. The specimen probably scavenged on human refuse (Gron 2013a). Two probable scenarios were suggested for the specimen: (1) it represented a domesticated outlier that was scavenging outside of the managed individuals at the site, or (2) it represented a single wild boar in the dataset that was likewise scavenging (Gron 2013a).

All four-dog specimens analysed in the study by Gron (2013a) yielded reliable data, and had a broad range in both their $\delta^{13}C$ (-19.7‰ to -9.5‰) and $\delta^{15}N$ (8.4‰ to 12.4‰) values. There were two different dietary groups of dogs at the Havnø kitchen midden, with one showing a diet that was predominantly derived from marine protein, and the second, represented by one specimen, showing a diet chiefly composed of terrestrial derived protein. It is more than likely that the diet of the second had been supplemented with varying quantities of aquatic derived protein as indicated by the elevated $\delta^{15}N$ value. Similarly, they may represent Mesolithic and Neolithic dogs at the kitchen midden.

Both the grey seal and the Phocidae specimens yielded reliable data (Gron 2013a), and had a broad range in both their $\delta^{13}C$ (-16.7‰ and -12.0‰) and $\delta^{15}N$ values (12.1‰ and 14.6‰). The grey seal possessed depleted $\delta^{13}C$ and $\delta^{15}N$ values than the unidentified Phocidae, which is indicative of residency and subsistence between typical freshwater and marine carbon pools, probably the Baltic Sea (Craig *et al*. 2006). The Phocidae specimen possessed more elevated $\delta^{13}C$ and $\delta^{15}N$ values indicative of the consumption of marine derive protein higher up in the trophic level hierarchy, and most probably represented an individual that fed and lived in the North Sea (Craig *et al*. 2006).

3.4.2. Sampling

As described in Chapter 2, kitchen middens have a complex depositional history. Despite modern excavation methodologies, determining the relative age of specimens across the

Havnø kitchen midden has proven to be problematic. In light of these issues the stable isotope samples analysed in the project were assigned to culture by association with ceramic and lithic typologies, matrix shell size, composition, location within the kitchen midden, and, in some cases by AMS radiocarbon dating (Gron 2013a). Regardless of these criteria, the separation between the EBK and TRB faunal remains at the kitchen midden is largely unresolved (Gron 2013a). Undoubtedly the on-going course of AMS radiocarbon dating will help to clarify these data in the future by securely dating the individual horizons from where the samples are derived from. Unfortunately, some of the samples analysed in this study remain undifferentiated to cultural epoch. Based on the available AMS radiocarbon dates on materials from the kitchen midden, the majority of the faunal remains, including the fish are almost certainly either EBK or Neolithic in age. Nevertheless there are a number of species in the dataset that can be assigned to culture based on their very presence, as, for example, domestic cattle has not been identified from Jutland prior to ca. 4000 cal BC (Noe-Nygaard and Hede 2006; Noe-Nygaard *et al*. 2005; Price and Noe-Nygaard 2009).

In addition, whilst it was attempted not to sample specimens that may represent residual or intrusive events, it cannot be stated unequivocally that all contexts were primary, given the repeated accumulation of materials at the kitchen midden in the region of 3000 radiocarbon years (Andersen 2008a). Equally it cannot be ruled out that some of the specimens may have resided far away from the Havnø island based on body part representation data from contemporaneous sites (Gron 2013b) and the presence of freshwater species of fish (Chapter 6) and molluscs (Demarchi personal communication 2015) in the assemblage.

3.4.2.1. Human remains

In total, 20 human skeletal elements derived from 12 different grid squares were sampled from multiple contexts across the kitchen midden (Figure 3.7). These data are presented in Appendix 2. Initial identification and sorting of the excavated material was performed in Denmark during the analysis of the faunal remains recovered from 2005 through 2011 (Gron 2013a). The one exception being AJEQ that was discovered in 2012 and subsequently identified, and sorted by Søren H. Andersen in Denmark. In 2011 the majority

of the human remains were brought to The University of York for osteological assessment, stable isotope analysis, and AMS radiocarbon dating by the author. However, AJEQ was selected from the Havnø collection in the stores at Moesgård Museum, and taken to the same institution by the author in 2014. While the data from the osteological analysis has been published in a preliminary form, it has been made available (Hellewell 2012a). In general the human remains from the site were highly fragmentary, making assessment of the minimum number of individuals (MNI) represented in the assemblage difficult. There was a noticeable absence of ribs and vertebrae with the exception of specimen AJEQ. Only a minimum number of three individuals could be established through osteological analysis based on age criteria out of the 52 skeletal elements analysed by Hellewell (2012a): one adult, one adolescent, and one juvenile. However, permission to sample the adolescent was not obtained, and it remains housed at the Zoological Museum, Copenhagen. Despite the fact that this individual is represented by only the one skeletal element (JD), identified as an incomplete radius that precluded siding since both epiphyses were unfused, it is possible that it belonged to a younger individual, i.e. the juvenile. Thus, it was only possible to sample skeletal elements belonging to two out of the three individuals identified in the assemblage.

Initially the human remains were sampled according to their spatial distribution. As such the sampling strategy took into consideration the possibility of multiple individuals interred at the kitchen midden, and favoured specimens that maximized the potential for ascertaining additional individuals not identified during the osteological analysis as has been demonstrated previously (Brinch Petersen 1974). Samples were chosen with the assumption/hope that they were of EBK date given that approximately 40% of the kitchen midden material has been dated to this culture (Søren H. Andersen personal communication 2013). In reality some of these samples produced late Neolithic dates. However, they still provide useful information for examining the character, extent and intensity of dietary changes across the Mesolithic-Neolithic transition that can be used in wider dietary debates (Fischer *et al*. 2007; Milner and Craig 2012).

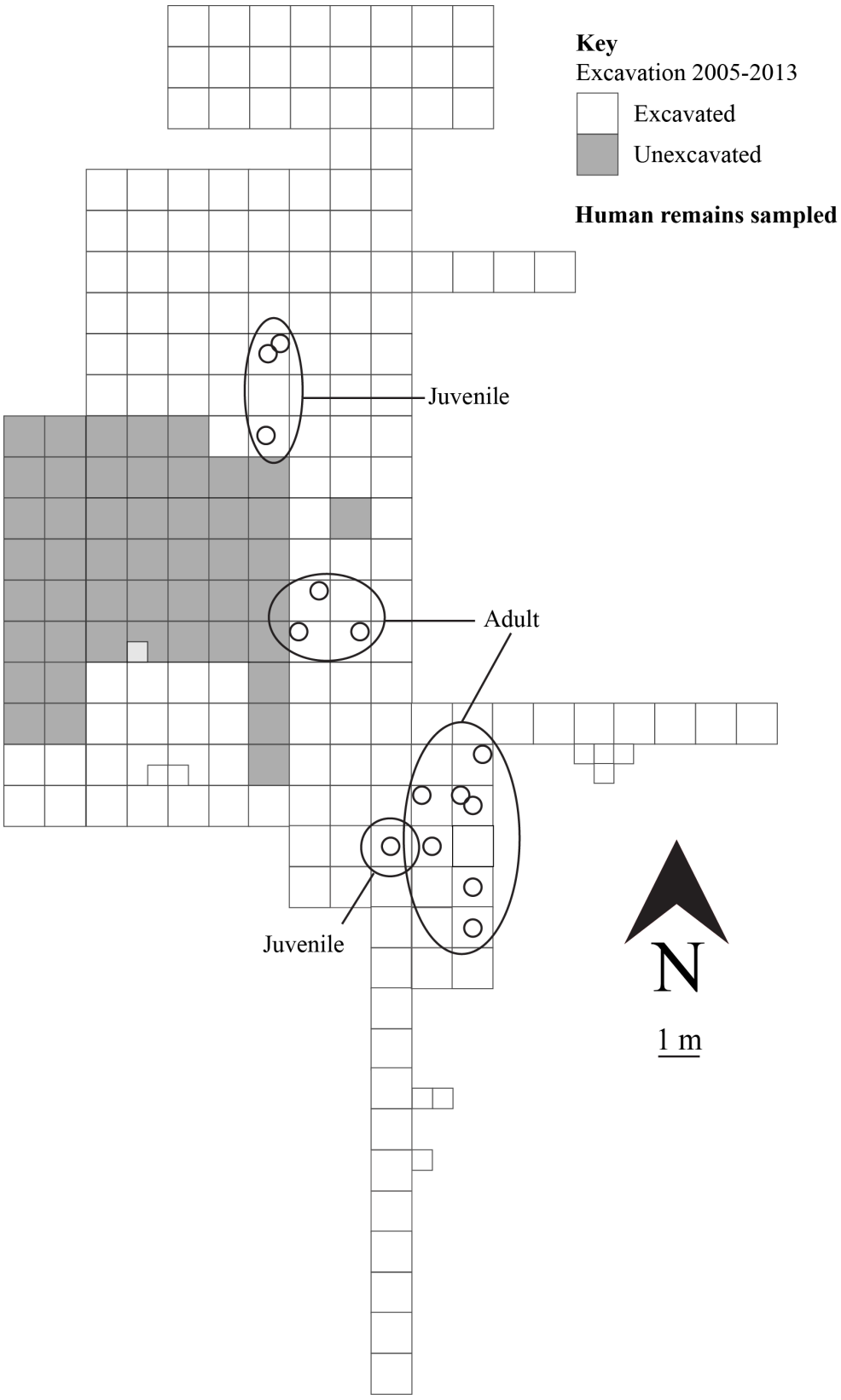


Figure 3.7: The full extent of the Havnø excavations and the human remains sampled in this study.

3.4.2.2. Fish remains

The fish remains were derived from multiple contexts throughout the kitchen midden. These data are presented in Appendix 2. The identification and sorting of the excavated material was performed in Denmark either during excavation or the analysis of the faunal remains recovered from 2005 through 2011 (Gron 2013a). The sampling strategy was largely built on a previous study (Robson 2010). Initial selection took into consideration the possibility of multiple individuals, thus the fish bones were sampled according to their spatial distribution. In addition, skeletal elements were selected in order to reduce the chances of sampling the same individual. Nevertheless, the possibility exists that some of the fish remains may derive from the same individual. For nine samples individual bones were too light, and thus it was necessary to take several skeletal elements in order to arrive at a weight whereby collagen could be successfully extracted.

In order to sample the most important taxa for reconstructing past human subsistence at Havnø, the sampling strategy for the fish remains was largely based on the number of identified specimens (Chapter 6). As such, the fish remains sampled encompassed a wide spectrum of freshwater, brackish, and marine taxa (n = 9), which represented variable life histories and habitat use. They included two taxa from the Cyprinidae family: roach (*Rutilus rutilus*, 0.7% of NISP) and unidentified Cyprinidae (1.0% of NISP) to provide a baseline for a freshwater environment. The marine environment was represented by one stenohaline species from the Scombridae family: mackerel (*Scomber scombrus*, 1.0% of NISP). In addition four euryhaline taxa were represented by the Scophthalmidae and Pleuronectidae families: unidentified Scophthalmidae/Pleuronectidae (1.7% of NISP), unidentified Pleuronectidae (5.2% of NISP), Pleuronectidae, cf. plaice (*Pleuronectes platessa,* 0.7% of NISP) and Pleuronectidae, cf. European flounder (2.7% of NISP) respectively. Diadromous fishes (those that migrate between salinity gradients) are present in the sample set, including European eel (61.4% of NISP) and unidentified Salmonidae (1.6% of NISP). The majority of the carbon and nitrogen isotope data from the European eel bone samples has been reported elsewhere (Robson *et al*. 2012).

3.4.2.3. Avian remains

A total of two specimens confidently identified as humeri (right and indeterminate) deriving from *Cygnus* sp. were sampled from the Thygeslund kitchen midden. It is more than likely that they represent at least two different individuals. The presence of swans at Havnø and Thygeslund attests to their importance as a sought after resource in the Mariager Fjord. Moreover they were the most represented genus of bird in both faunal assemblages (NISP of 75 and 6 respectively). Although the specimens studied here could not be further identified to the lower genus and species taxonomic levels, Bewick's swan (*Cygnus bewickii*) and whooper swan have both been identified in the assemblage from Havnø. They were selected to provide baseline stable isotope data of birds from the Mariager Fjord, and to complement the mammal remains analysed from Havnø that is located <5 km away.

Initial sorting of the faunal remains from Thygeslund was undertaken in 2013 in Denmark (Søren H. Andersen personal communication 2013). The subsequent analysis and identification was carried out at The University of Durham in 2014 by Gron (personal communication 2014). Similarly the Thygeslund faunal assemblage although in a fair condition is highly fragmented. In total, 539 avian, mammalian, and unidentifiable bones were analysed.

3.4.2.4. Mammal remains

While not a part of this thesis (Gron 2013a), 38 mammal remains recovered from Havnø have been included in order to establish the stable isotope values associated with marine and terrestrial diets at this specific locality, thus providing an ecological baseline for the interpretation of the human bone collagen stable isotope data. These included wild terrestrial herbivores represented by auroch, red deer and roe deer, as well as a terrestrial omnivore, unidentified *Sus*. Marine mammals were present in the sample set, including grey seal (*Halichoerus grypus*) and unidentified Phocidae. In addition domestic terrestrial herbivores were represented by cattle and an unidentified ovicaprid. While it was possible to determine the two auroch specimens to species based on diagnostic measurements (Degerbøl and Fredskild 1970), it was not possible to differentiate between the domestic and wild congeners of *Sus* due to the absence of diagnostic elements and measurements

(Gron 2013a).

3.4.2.5. Samples selected for sulphur isotope analysis

To complement the carbon and nitrogen stable isotope analysis, discriminate between the consumption of different resources, and establish the provenance of animals, a total of 10 samples were selected for sulphur stable isotope analysis. These data are presented in Appendix 2. In total four skeletal elements securely identified as human, and a wild terrestrial herbivore represented by roe deer (n = 2) were sampled. In addition, euryhaline and diadromous fishes were present in the sample set, which included two Pleuronectidae, cf. European flounder and two European eel bone samples.

3.5. AMS radiocarbon dating of faunal and human remains from Havnø

3.5.1. Previous analyses

Accelerator mass spectrometry radiocarbon dates have been obtained from 26 samples taken in association with the excavations at the Havnø kitchen midden. These data have been made available by Andersen (personal communication 2014) and Gron (2013a). They are listed in Appendix 2.

3.5.2. Sampling

3.5.2.1. Human remains

Five human remains were AMS radiocarbon dated as a part of this study to: (1) contextualize the stable isotope data, and to at least in part determine those individuals dating to the Mesolithic and/or Neolithic periods, and (2) identify potentially different depositional events related to their spatial distribution.

3.5.3. Phase and sequence

The stratigraphical relationship between the samples was based on their location within the kitchen midden. Thus they were collated according to the following groups: (1) the eastern

portion of the midden proper, (2) the central part of the midden proper, (3) the western portion of the midden proper, and (4) the outlying squares to the north of the midden proper (Figure 3.8). In addition, the sequential deposition of the samples was established according to level within the midden sequence.

3.6. Methods

3.6.1. Sample selection for collagen extraction

Including previous analyses (Gron 2013a; Robson *et al*. 2012) a total of 100 archaeological mammal, fish and human remains recovered from the Havnø kitchen midden were selected for carbon, nitrogen and sulphur stable isotope analyses. In general, the specimens were selected based on their overall appearance, weight, and likelihood of deriving from different individuals, except for some of the fish and human remains. Nevertheless, there is a possibility that some of the faunal remains are derived from the same individual, but this is unlikely for the majority (Gron 2013a).

Where possible, large (>500 mg) skeletal elements were selected so that a single specimen would be sufficient for collagen extraction including carbon, nitrogen and sulphur stable isotope analyses (Appendix 2). However, for certain taxa, especially multiple fish bone samples, individual bones were too light and thus it was necessary to take several skeletal elements in order to arrive at a weight of between 100-300 mg (Szpak *et* 2011). This was especially true for the eel bone samples, and in these cases numerous small skeletal elements were selected for analysis. In doing so the bones were always taken from the same closed stratigraphical context that would reduce the chances of multiple individuals, although this assumption cannot be ruled out completely. The fish bones were identified by side-by-side comparison with modern reference skeletons of known taxon (Chapter 6).

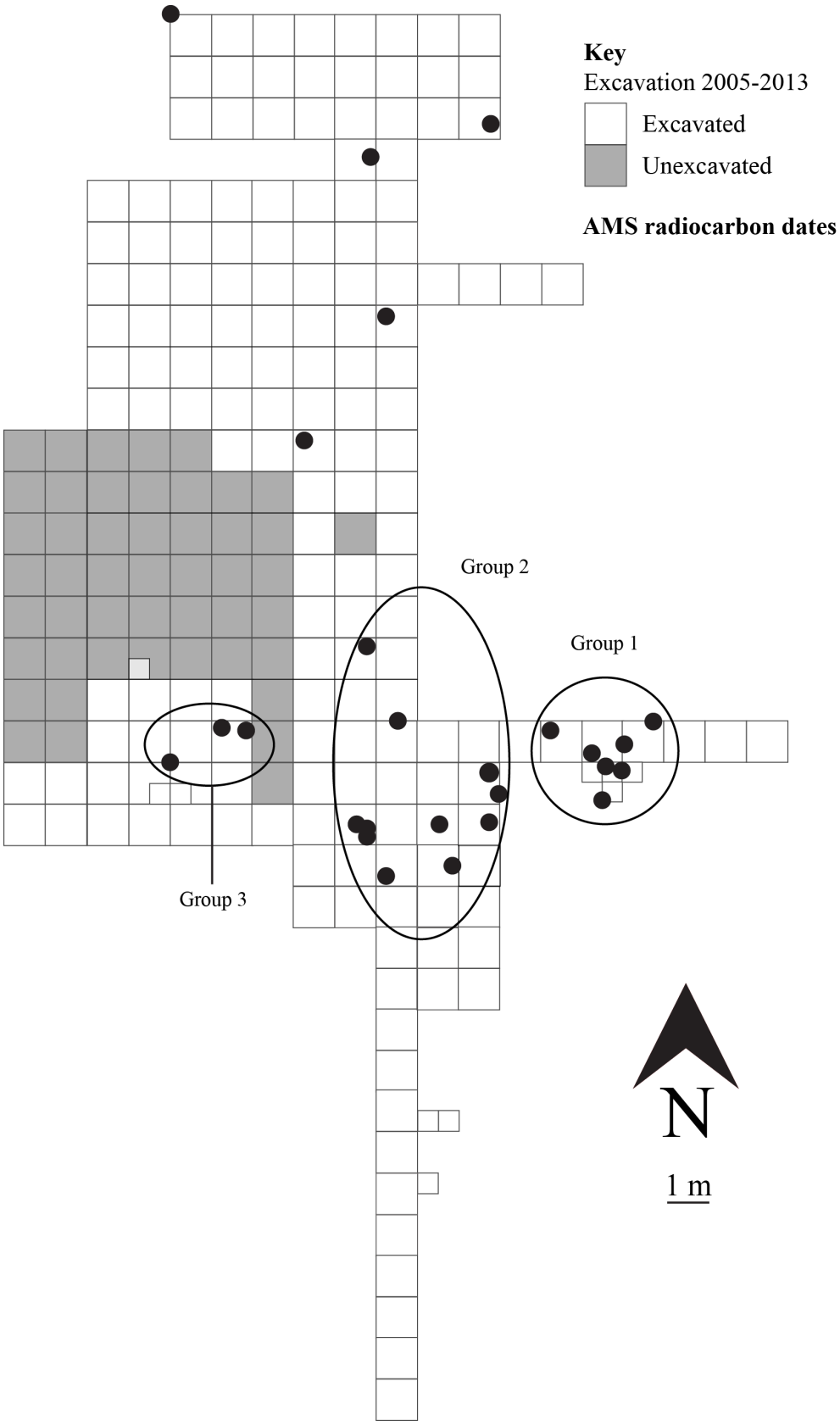


Figure 3.8: The full extent of the Havnø excavations and the locations of samples for dating.

3.6.2. Collagen extraction and EA-IRMS

The following provides a summary of collagen and Elemental Analysis-Isotope Ratio Mass Spectrometry (EA-IRMS). The Standard Operating Procedure (SOP) for collagen extraction at The University of York is presented in Appendix 2.

Carbon, nitrogen and sulphur stable isotope analyses were undertaken by EA-IRMS. The extraction procedures for bone collagen were largely based on the methods described by Brown *et al*. (1988), DeNiro and Epstein (1981), Longin (1971), and Richards and Hedges (1999). In this study archaeological sample preparation was carried out at the BioArCh laboratories of The University of York (UK), whereas in the study by Gron (2013a) they were undertaken at the Copenhagen University Department of Geology and Geography (Denmark). Hydroxyapatite analyses were not included due to the potential for diagenesis, and therefore all dietary interpretations are based only on the protein component of the diet (White *et al*. 2001). In this study carbon and nitrogen stable isotopic ratio measurements were undertaken at the Division of Archaeological, Geographical and Environmental Sciences at The University of Bradford, and The University of York (UK). In the study by Gron (2013a) measurements were performed at The University of Waterloo Environmental Isotope Laboratory (Canada), and the Chrono Centre at The Queen's University Belfast (UK). The sulphur stable isotopic ratio measurements were carried out at Iso-Analytical Limited (Crewe, UK).

For carbon and nitrogen stable isotope analysis, shards of bone weighing approximately 200-300 mg were removed from the original specimen, while shards weighing >500 mg were used for sulphur stable isotope analysis. The human and faunal remains were surfaced cleaned using a Dremel™ (Mount Prospect, USA) modelling drill fitted with tungsten carbide tipped bit or equivalent. Since the majority of the fish remains were delicate, fragile and small they were not cleaned of surface contamination, as this would have damaged the samples. Each specimen was demineralised at ca. 4°C in 8 ml of either 0.1 or 0.6 M HCl depending upon the size of the individual specimen in question. In general the fish remains were demineralised in 8 ml of 0.1 M HCl due to their delecate nature (Robson *et al*. 2012, 2015). Once demineralised, the samples were rinsed to neutrality three times in de-ionised

water, and the pH measured to check for acid. The samples were then placed in an oven at ca. 80°C in pH3 HCl for 48 hours to gelatinise. The samples were centrifuged and the supernatant was ultra-filtered to isolate the >30 kDa fraction (Brown *et al*. 1988). Finally, samples were freeze-dried.

To determine the $\delta^{13}C$ and $\delta^{15}N$ isotopic values, duplicates between 0.8 and 1.2 mg of the extracted collagen was weighed into tin capsules for analysis in either a Roboprep Combustion Device coupled to a Europa 20-20 Mass Spectrometer (PDZ_Europa, Crewe, UK), or a Sercon GSL analyser coupled to a Sercon 20-22 Mass Spectrometer (Sercon, Crewe, UK).

To determine the $\delta^{34}S$ isotopic ratios, duplicates, where possible, weighing approximately 8 mg of the extracted collagen were weighed into tin capsules, and combusted with additional vanadium oxide (V_2O_5), and a pulse of oxygen to ensure complete combustion. The resulting gases, sulphur monoxide (SO) and sulphur dioxide (SO_2), were analysed on a Europa Scientific 20-20 isotope ratio Mass Spectrometer (PDZ_Europa, Crewe, UK). The samples were measured relative to the international V-CDT standard using a number of in-house standards, IA-R061 (barium sulfate, $\delta^{34}S_{V\text{-}CDT}$ = +20.33‰), IA-R025 (barium sulfate, $\delta^{34}S_{V\text{-}CDT}$ = +8.53‰), and IA-R026 (silver sulfide, $\delta^{34}S_{V\text{-}CDT}$ = +3.96‰), calibrated and traceable to the international NBS-127 (barium sulfate, $\delta^{34}S_{CDT}$ = +20.3‰), as well as the international IAEA-S-1 (silver sulfide, $\delta^{34}S_{V\text{-}CDT}$ = -0.3‰).

The carbon, nitrogen and sulphur stable isotope values are all expressed in parts per thousand or per mil (‰) and designated by the delta notation (δ). Several analyses were run in conjunction with AMS radiocarbon dating.

3.6.3. Quality controls for EA-IRMS

3.6.3.1. Carbon and nitrogen stable isotope analysis

Following standard procedures the samples were measured relative to the international V-PDB standard (for $\delta^{13}C$) and the international AIR standard (for $\delta^{15}N$) using a number of

laboratory standards that were analysed simultaneously with each sample group to ensure instrument integrity (Richards and Hedges 1999). These included BLS (bovine liver standard, $\delta^{13}C_{V\text{-}PDB}$ = -21.59 ± 0.25, $\delta^{13}N_{AIR}$ = +7.65 ± 0.25), fish gelatine ($\delta^{13}C_{V\text{-}PDB}$ = -15.52, $\delta^{13}N_{AIR}$ = +14.45), and methionine ($\delta^{13}C_{V\text{-}PDB}$ = -26.6, $\delta^{13}N_{AIR}$ = -3.0) traceable to international isotope reference standards, including IA BEET ($\delta^{13}C_{V\text{-}PDB}$ = -26.03 ± 0.11), IA CANE ($\delta^{13}C_{V\text{-}PDB}$ = -11.64 ± 0.03), IAEA 600 ($\delta^{13}C_{V\text{-}PDB}$ = -27.77 ± 0.04, $\delta^{13}N_{AIR}$ = +1.0 ± 0.2), IAEA N1 ($\delta^{13}N_{AIR}$ = +0.4 ± 0.2), and IAEA N2 ($\delta^{13}N_{AIR}$ = +20.3 ± 0.2). The values measured during the analysis were -21.59 ± 0.15 and +7.55 ± 0.19 (1σ, *n* = 28) for BLS, -15.57 ± 0.26, and +14.37 ± 0.28 (1σ, *n* = 62) for fish gelatine, -26.63 ± 0.16, and -3.01 ± 0.39 (1σ, *n* = 29) for methionine, -26.10 ± 0.05 (1σ, *n* = 6) for IA BEET, -11.86 ± 0.13 (1σ, *n* = 12) for IA CANE, -27.71 ± 0.28, and +0.98 ± 0.28 (1σ, *n* = 50) for IAEA 600, +0.34 ± 0.10 (1σ, *n* = 4) for IAEA N1, as well as +20.58 ± 0.12 (1σ, *n* = 12) for IAEA N2. To summarise, analytical error, calculated from the repeated measurements of the international, and in-house standards from multiple extracts between laboratories was <0.2‰ (1σ).

3.6.3.2. Sulphur stable isotope analysis

For quality control purposes additional samples of IA-R061, IAEA-SO-5 (barium sulfate, $\delta^{34}S_{V\text{-}CDT}$ = +0.50‰), and NBS-1577B (powdered bovine liver, $\delta^{34}S_{V\text{-}CDT}$ = +7.50‰) were analysed simultaneously with the batch of samples. The values measured during the analysis were +20.39 ± 0.04 (1σ, *n* = 4) for IA-R061, +0.66 ± 0.00 (1σ, *n* = 2) for IAEA-SO-5, and +7.35 ± 0.03 (1σ, *n* = 2) for NBS-1577B.

3.6.3.3. Inter-laboratory comparison

Table 3.2 summarises the $\delta^{13}C$ and $\delta^{15}N$ values, as well as the C:N atomic ratios for 10 of the 20 human remains that were measured at two institutions: Bradford and York. Comparison between the laboratories was deemed satisfactory. The mean and standard deviations between Bradford and York was 0.0‰ ± 0.2‰ for $\delta^{13}C$, -0.1‰ ± 0.2‰ for $\delta^{15}N$, and 0.0‰ ± 0.0‰ for the C:N atomic ratio. The inter-laboratory deviations are within the experimental errors reported by Pestle *et al*. (2014).

University of Bradford				**University of York**				**Comparison**		
Lab. no.	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**	**C:N**	**Lab. no.**	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**	**C:N**	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**	**C:N**
QEKb+c	-11.7	13.6	3.2	QEKa+b	-11.6	13.5	3.2	-0.1	0.0	0.0
THEa+b	-11.8	13.6	3.2	THEa+b	-11.9	13.3	3.2	0.1	0.2	0.0
OHAa+b	-11.7	13.2	3.2	OHAa+b	-11.6	13.5	3.1	-0.1	-0.3	0.0
OTDa+b	-11.5	13.3	3.2	OTDa+b	-11.6	13.5	3.2	0.0	-0.2	0.0
OHL3a+b	-11.6	13.1	3.1	OHL3a+b	-11.8	13.5	3.2	0.2	-0.3	0.0
UDEa+b	-11.3	13.0	3.2	UDEa+b	-11.5	13.2	3.2	0.1	-0.3	0.0
UBQAa+b	-12.1	13.5	3.3	UBQAa+b	-11.6	13.5	3.2	-0.4	0.1	0.1
LDUAa+b	-11.8	13.5	3.2	LDUAa+b	-12.0	13.2	3.2	0.2	0.3	0.0
QQBa+b	-18.2	11.3	3.2	QQBa+b	-18.2	11.4	3.1	0.0	-0.2	0.0
XPGa+b	-17.9	12.5	3.2	XPGa+b	-18.1	12.4	3.2	0.2	0.0	0.0
								0.0	-0.1	0.0
								0.2	0.2	0.0
							Mean	**0.0**	**-0.1**	**0.0**
							STDV (± 1σ)	**0.2**	**0.2**	**0.0**

Table 3.2: Comparison between analyses undertaken at the University of Bradford and the University of York. Although some of the differences were greater than 0.2‰, they are not on the level of dietary interpretation.

3.6.4. Food Reconstruction Using Isotopic Transferred Signals

The main aim for the application of FRUITS was to determine the contribution of the individual food groups toward a consumer's diet (Fernandes *et al*. 2014). After initial experiments with numerous food groups, it was decided to use the one dietary scenario. Thus, this was achieved by utilising the carbon and nitrogen stable isotope data obtained on fish and terrestrial mammal bone collagen. Thus, the stable isotope data was averaged and grouped according to taxa, and included marine fish (European eel, flatfish and Atlantic mackerel), terrestrial mammals (auroch, red deer, roe deer and *Sus* sp. for the Mesolithic individuals and cattle, ovicaprid, red deer, roe deer and *Sus* sp. for the Neolithic individuals), as well as cereals (for the Neolithic individuals) or wild plants (for the Mesolithic individuals). The cereals and wild plants had identical stable isotope data. Although manuring can elevate the $\delta^{15}N$ values of cereals, it had not been undertaken on the TRB cereals derived from Denmark that were analysed by Bogaard *et al*. (2013).

Given the differential dietary routing of macronutrients, two parameters (protein and energy that was the collation of carbohydrates and lipids) were set since both fractionate from diet to bone collagen.

The dietary proxy signals represented the stable isotope values measured on the consumer tissues, and included carbon and nitrogen.

The consumer data referred to the measured carbon and nitrogen stable isotope values and standard deviations obtained on human bone collagen.

The food groups' parameter refers to the nomenclature used to quantify a consumer's diet and included marine fish, terrestrial mammals and cereals/wild plants.

Likewise the food fractions' parameter refers to the nomenclature of macronutrients towards whole diet and included protein and energy (carbohydrates and lipids).

Recently multiple regression analysis on previously published data by Fernandes *et al*.

(2012) has provided an empirical macronutrient-based model for dietary carbon routing in bone collagen. The collagen synthesis model suggested that the $\delta^{13}C$ values obtained from bone collagen are determined by relatively fixed contributions from the different macronutrients, which are estimated at ~76% protein and ~24% energy (carbohydrates and lipids). In this study the estimations were largely similar for carbon, however the model parameter protein concentration, that is, the offset and weights for nitrogen was set at 100% (Appendix 2).

The food values parameter refers to the measured carbon and nitrogen stable isotope values and standard deviations obtained from the food groups. It is assumed that protein is enriched compared to energy (carbohydrates and lipids), therefore in this model the carbon, and nitrogen values obtained from marine fish and terrestrial mammal bone collagen are elevated by 6‰, whereas the cereal value is elevated by 1‰ (Fernandes 2015).

The concentrations of protein and energy for the individual food groups were identical to those reported by Fernandes (2015).

Unlike SIAR prior information can be applied in FRUITS, that is, assumptions on the relative intake of macronutrients. While the prior information resulting from metabolic and physiological studies can improve the overall precision, assumptions can be posited. It is assumed that certain food groups or food fractions contributed more than others to the consumer's diet, for instance the proportion (represented by NISP) of a particular taxon within an archaeological assemblage. However, given the uncertainty, *a priori* constraints were not applied.

3.6.5. Calibration of the AMS radiocarbon dates

One of the problems during the interpretation of AMS radiocarbon data has been to assess the impact of the potential reservoir effect. In order to correct for the MRE, it was necessary to determine the proportion (%) of marine carbon in bone collagen as accurately as possible. This was achieved for the domesticated dog, human and seal bone collagen samples by applying a rudimentary linear model (Arneborg *et al*. 1999) with the estimated

endpoints of -21.7‰ and -10.1‰, corresponding to 0% and 100% marine diet, respectively (Fischer *et al*. 2007). Since the analyses by Arneborg *et al*. (1999) were performed on Greenlander Vikings the model is applicable to the present study. Once undertaken the calibrated age ranges in calendar years were determined using the University of Oxford Radiocarbon Accelerator Unit calibration programme OxCal 4.2 (Bronk Ramsey 2009). The terrestrial samples were calibrated using the IntCal13 curve while marine samples were calibrated using the Marine13 curve (Reimer *et al*. 2009), and by applying a marine reservoir correction of 431 ± 42 years (ΔR) based on local marine mollusc data that was derived from a digital resource, the ^{14}CHRONO Centre, Queens University Belfast (Cook *et al*. 2015; www.calib.qub.ac.uk).

3.7. Results

3.7.1. Carbon and nitrogen stable isotope analysis

In this study a total of 40 samples were prepared for analysis. Of these, 37 (92.5%) produced sufficiently well preserved collagen for reliable measurement and had C:N atomic ratios that were within the acceptable range of 2.9-3.6 (DeNiro 1985; Szpak 2011). Two samples did not produce sufficient quantities of collagen for analysis, whereas two had C:N atomic ratios that were outside of the approved range, as such they are excluded from further analysis (Szpak 2011; van Klinken 1999). A full listing of the stable isotope data is provided in Appendix 2. The summary statistics for each category of fish and humans included in this study are shown in Table 3.3.

3.7.1.1. Human remains

All 20 samples produced sufficiently well preserved collagen for reliable measurement. However, one sample is unlikely to be human, and probably represents a terrestrial mammal. Although specimen H-XGX was identified as human during the osteological analysis (Hellewell 2012a) it is a clear outlier when compared to the other 19 samples (Figure 3.9). It had a δ^{15}N value of 4.3‰ that plots alongside the domesticated and wild terrestrial mammals. The human bone isotope data are plotted collectively in Figure 3.9, and by MNI in Figure 3.11.

Sample Group **Havnø**	Sample size	Mean $\delta^{13}C_{V\text{-}PDB}$ (‰) ± STDV (+ 1σ)	Mean $\delta^{15}N_{AIR}$ (‰) ± STDV (+ 1σ)
Humans - all	19	-14.0 ± 3.3	12.9 ± 1.1
Humans - Ertebølle	12	-11.8 ± 0.3	13.5 ± 0.3
Humans - Funnel Beaker	5	-19.0 ± 1.4	11.4 ± 1.0
Humans – unknown epoch	2	-15.0 ± 0.1	13.4 ± 0.1
Humans - adults	15	-12.8 ± 2.5	13.2 ± 1.0
Humans - juveniles	4	-18.5 ± 1.0	11.8 ± 0.5
Human - adult (1)	1	-21.0	9.9
Human - adult (2)	12	-11.8 ± 0.3	13.5 ± 0.3
Human - adult (3)	2	-15.0 ± 0.1	13.4 ± 0.1
Human - juvenile (1)	3	-18.0 ± 0.2	11.7 ± 0.6
Human - juvenile (2)	1	-20.0	11.8
Fish – all	28	-11.9 ± 4.4	8.2 ± 1.7
Fish – eel*	13	-9.1 ± 1.4	8.4 ± 0.8
Fish - Cyprinidae	2	-20.5 ± 10.2	7.5 ± 3.2
Fish - flatfish	11	-12.9 ± 2.8	7.8 ± 2.2
Fish - mackerel	1	-14.1	10.5
Fish - Salmonidae	1	-18.5	11.0
Fish – anadromous	14	-9.8 ± 2.8	8.6 ± 1.0
Fish – freshwater	2	-20.5 ± 10.2	7.5 ± 3.2
Fish – marine	12	-13.0 ± 2.7	8.0 ± 2.2
Thygeslund			
Bird – all waterfowl	2	-19.3 ± 0.3	4.4 ± 0.1

*Table 3.3: Summary statistics for the various categories of fish and humans included in this study. *Note that the majority of the eel remains (n = 11) have been reported elsewhere (Robson et al. 2012).*

While it was only possible to analyse two of the three human individuals that were identified in the assemblage (Hellewell 2012a), the carbon and nitrogen stable isotope data demonstrated that there were several human individuals in the sample set (Figure 3.8). Based on the range of the $\delta^{13}C$ and $\delta^{15}N$ values that were of the order of ± 1‰ (DeNiro and Schoeniger 1983; Pestle *et al*. 2014) a total of six different human individuals were likely present in the assemblage: one adolescent (not sampled), three adults, and two juveniles (Figure 3.9).

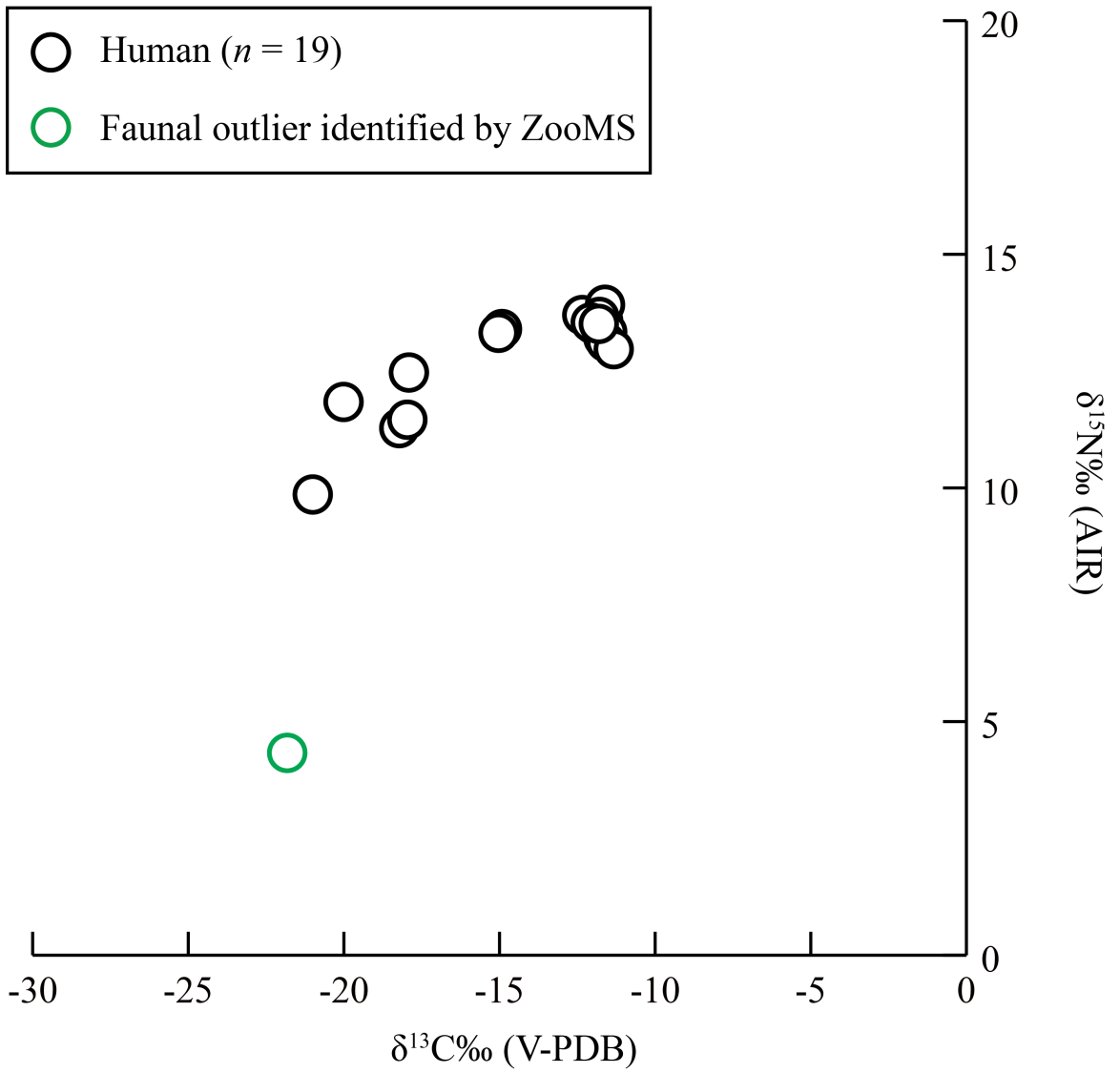


Figure 3.9: Carbon and nitrogen stable isotope data obtained on human bone collagen from the Havnø kitchen midden as well as the single mammal outlier that was confirmed by peptide mass fingerprinting (Buckley and Kansa 2011; Buckley et al. 2009).

On the whole the stable isotope data demonstrated differences in the long-term diets of the human individuals. Adult (1) had $\delta^{13}C$ and $\delta^{15}N$ values consistent with a diet that was largely composed of terrestrial derived protein, and may date to the Neolithic. The diet was probably supplemented by varying quantities of aquatic derived protein as indicated by a slightly elevated $\delta^{15}N$ value. Adult (2) was consistent with a diet that was chiefly composed of marine derived protein, notably resources that were higher up in the trophic level hierarchy. Adult (3) had an intermediary diet that was between the pure marine and

terrestrial endpoints of -21.7‰, and -10.1‰ respectively (Fischer *et al*. 2007). It is likely that this individual consumed protein derived from resources that were higher up in the trophic level hierarchy. Of the remaining five human remains identified as juvenile, four belonged to two different individuals, whilst one is without a doubt an incorrect identification. Peptide mass fingerprinting (ZooMS) undertaken at The University of York revealed that sample XGX was not human (Figure 3.10). The presence of m/z 1453.7 in the spectrum was characteristic of swine (Buckley and Kansa 2011).

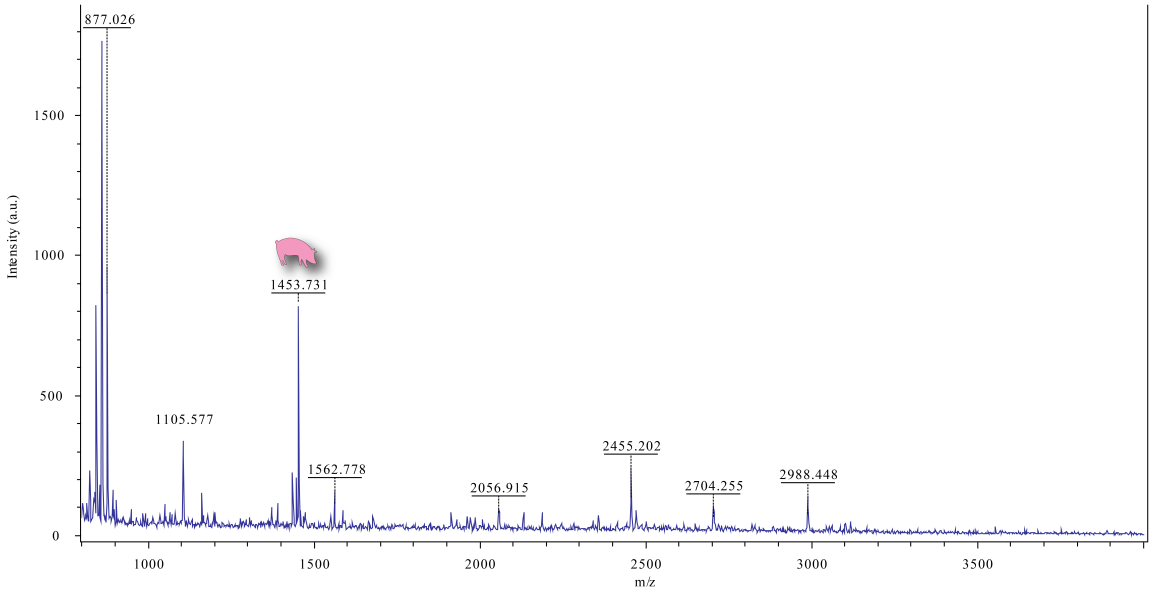


Figure 3.10: Mass spectra obtained from sample XGX.

Both juveniles (1) and (2) had $\delta^{13}C$ and $\delta^{15}N$ values consistent with terrestrial derived protein. In a similar manner to adult (1), their diets were probably supplemented by varying quantities of aquatic derived protein as demonstrated by their elevated $\delta^{15}N$ values. In general the data probably represent Mesolithic and Neolithic individuals that were deposited at the kitchen midden rather than later intrusions.

3.7.1.2. Fish remains

In total 17 out of 20 samples produced sufficiently well preserved collagen for reliable measurement (DeNiro 1985; Szpak 2011). The fish bone stable isotope data from Havnø are plotted in Figure 3.12.

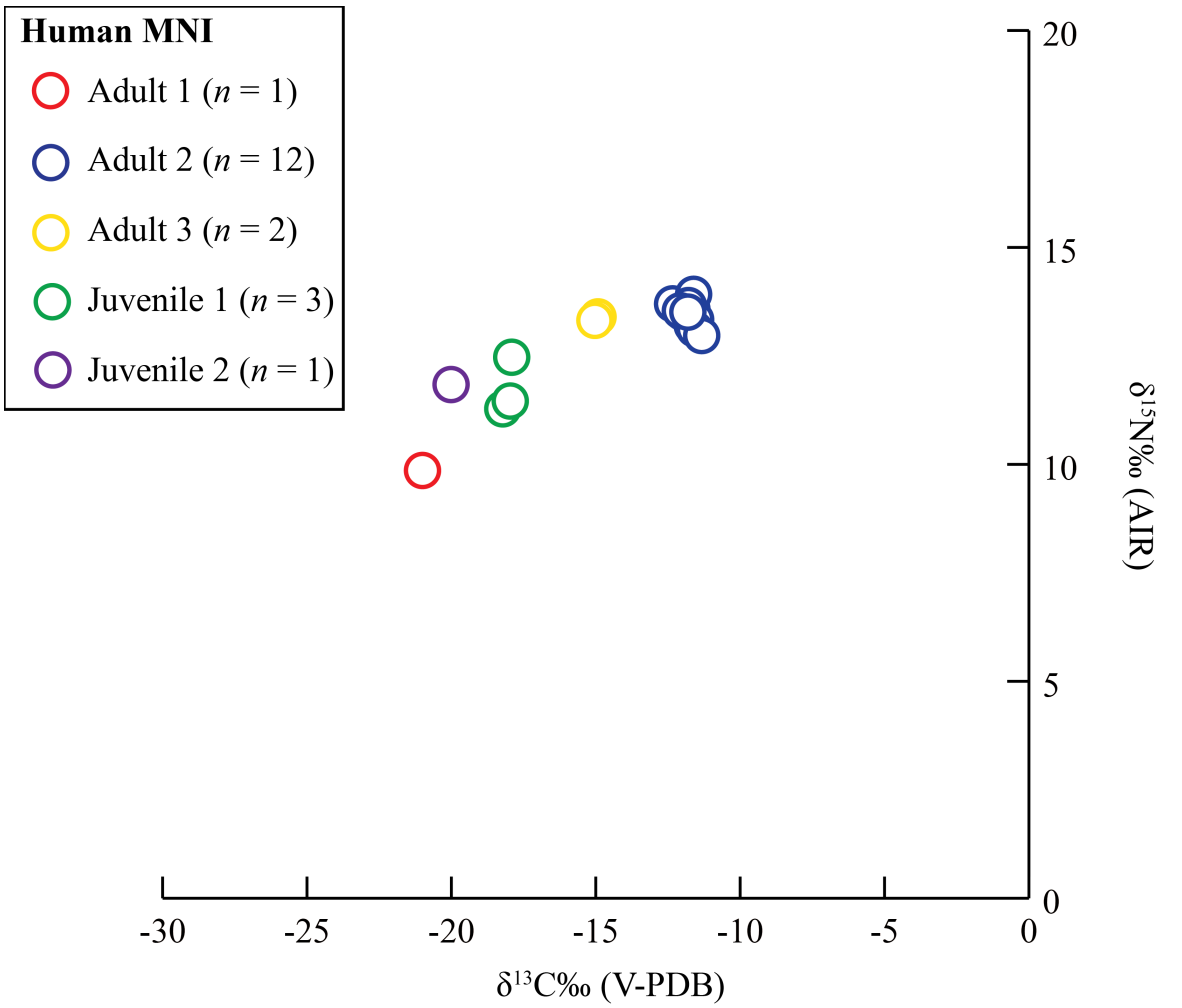


Figure 3.11: Carbon and nitrogen stable isotope data obtained on human bone collagen from the Havnø kitchen midden showing the minimum number of individuals.

The six taxa analysed in this study, and those eel reported by Robson *et al*. (2012) had a broad range in both their $\delta^{13}C$ (-27.7‰ to -6.9‰) and $\delta^{15}N$ values (5.1‰ to 11.8‰), indicating that these fish were on average feeding at 1.9 trophic levels higher than their producers in these diverse aquatic environments (difference/3.5). With the exception of the data obtained from the unidentified Cyprinidae, the data show a clear difference in the $\delta^{13}C$ values between the freshwater taxon, roach, and the brackish/marine, anadromous and catadromous species of fish recovered from the kitchen midden.

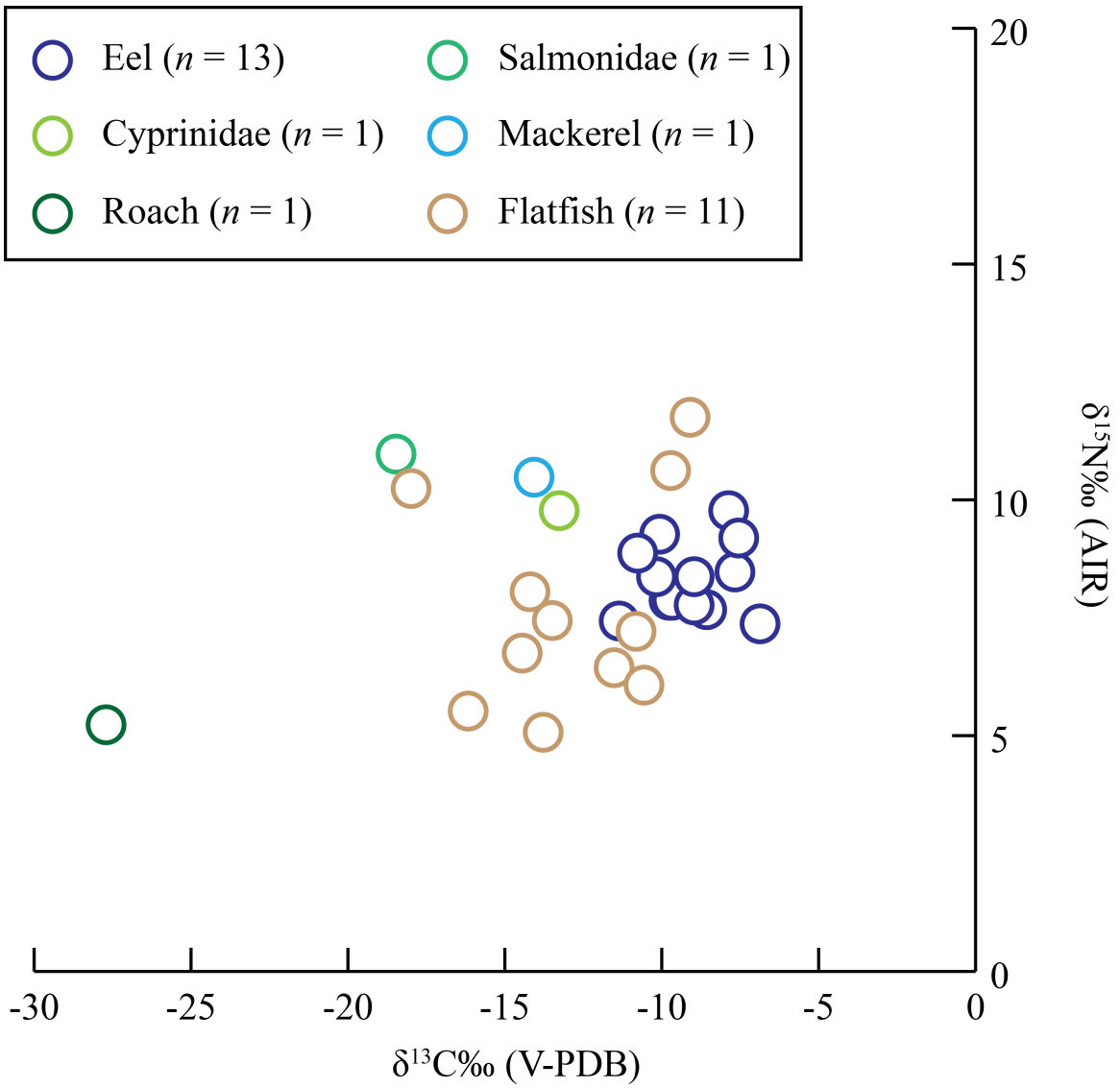


Figure 3.12: Carbon and nitrogen stable isotope data obtained on fish bone collagen from the Havnø kitchen midden as well as the eel data obtained by Robson et al. (2012).

The data obtained from the two eel specimens are consistent with those reported by Robson *et al*. (2012, accepted) from a number of archaeological sites in southern Scandinavia. In addition, when their estimated TL's and $\delta^{15}N$ values are plotted (Figure 3.13) there was a positive correlation. The one Cyprinidae specimen that could not be further identified taxonomically had a $\delta^{13}C$ value consistent with no evidence of freshwater residency, and a $\delta^{15}N$ value that was higher than the eel. The one roach sampled possessed a $\delta^{13}C$ value indicative of residency in a freshwater carbon pool, and a $\delta^{15}N$ value reflecting a diet of benthic invertebrates, zooplankton, plant material and detritus (Froese and Pauly 2015), and

thus, lower down in the trophic level hierarchy. The single unidentified Salmonidae specimen had a $\delta^{13}C$ value that was intermediate between freshwater and marine carbon pools, and a $\delta^{15}N$ value that was higher up in the trophic level hierarchy than the eel, Cyprinidae, roach, mackerel and the majority of the flatfish. The specimen could have belonged to either the Atlantic salmon (*Salar salar*) or sea trout (*Salmo trutta*) since they are known to migrate between carbon pools in order to spawn (Muus and Dahlstrøm 1964). Since mackerel are a pelagic migratory species, it is not surprising that the $\delta^{13}C$ value is consistent with marine residency. In addition, they are piscivorous although not particularly high in the trophic level hierarchy that is reflected by the $\delta^{15}N$ value. While a number of Scopthalmidae (left eye flounders) and Pleuronectidae (right eye flounders) species are known to naturally reside in the waters off the Danish coastline, not all of the specimens analysed in this study could be further identified to the lower taxonomic levels. The 11 flatfish exhibited variation in both their $\delta^{13}C$ and $\delta^{15}N$ values. Three distinctive groups are represented with one (n = 8) showing a largely demersal subsistence as indicated by their depleted $\delta^{15}N$ values, a second (n = 2) with elevated $\delta^{13}C$ and $\delta^{15}N$ values that are higher than the eel, Cyprinidae and mackerel, and a third (n = 1) with the most depleted $\delta^{13}C$ value, and an elevated $\delta^{15}N$ value that is lower than group two.

3.7.1.3. Bird remains from Thygeslund

The two swans that are derived from the coeval kitchen midden at Thygeslund possessed similar stable isotope values (Figure 3.14). The $\delta^{15}N$ values indicate that they were feeding lower down in the trophic level hierarchy, and as such are comparable with the domesticated and wild C_3 terrestrial mammals. However, they had slightly elevated $\delta^{13}C$ values that probably reflect the consumption of aquatic plants and grass of marine origin in particular.

3.7.2. Food Reconstruction Using Isotopic Transferred Signals results

The Bayesian mixing model FRUITS was used in order to accurately reconstruct the whole diet of the five individuals identified by carbon and nitrogen stable isotope analysis. The assumed scenario was based on the most accurate assimilation of the available resources to the assumed Mesolithic and Neolithic individuals interred at the kitchen midden (Figure

3.15).

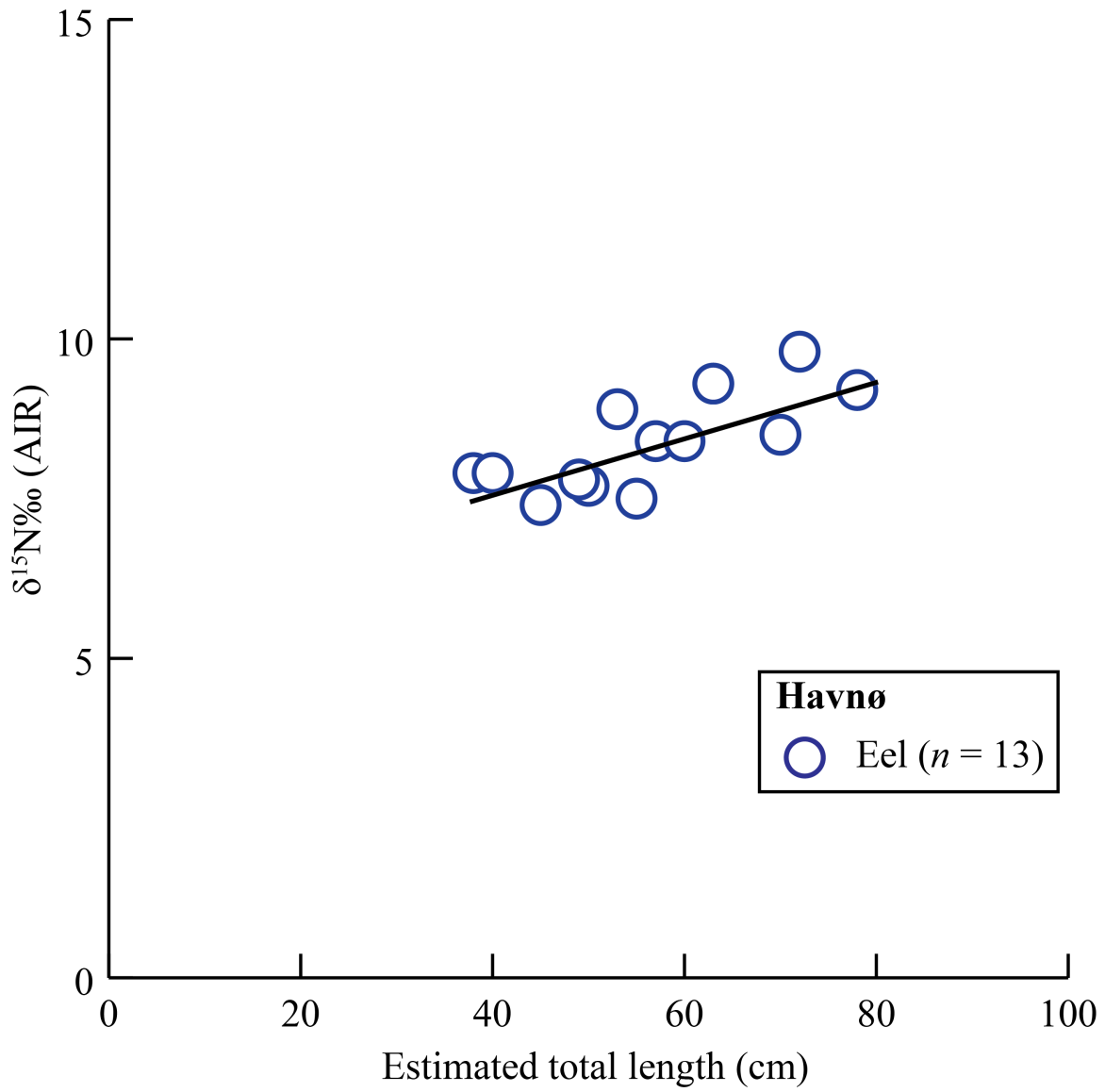


Figure 3.13: Estimated total length against nitrogen stable isotope data obtained from 13 eel specimens from the Havnø kitchen midden (partly after Robson et al. 2012).

The estimates on the signal contribution from food for the assumed scenario are listed in Appendix 2. The results obtained from each human individual for the scenario are plotted as box and whisker plots, and as probability distributions in Figures 3.16-3.25. The boxes represented the 68% credible interval, whereas the whiskers a 95% credible interval. The credible interval for the boxes corresponded to the 16th and 84th percentiles, while the

credible interval for the whiskers corresponded to the 2.5th and 97.5th percentiles. The dashed line demarcated the estimated mean, and the discontinuous line the estimated median that was, the 50th percentile (Fernandes *et al*. 2014, 7).

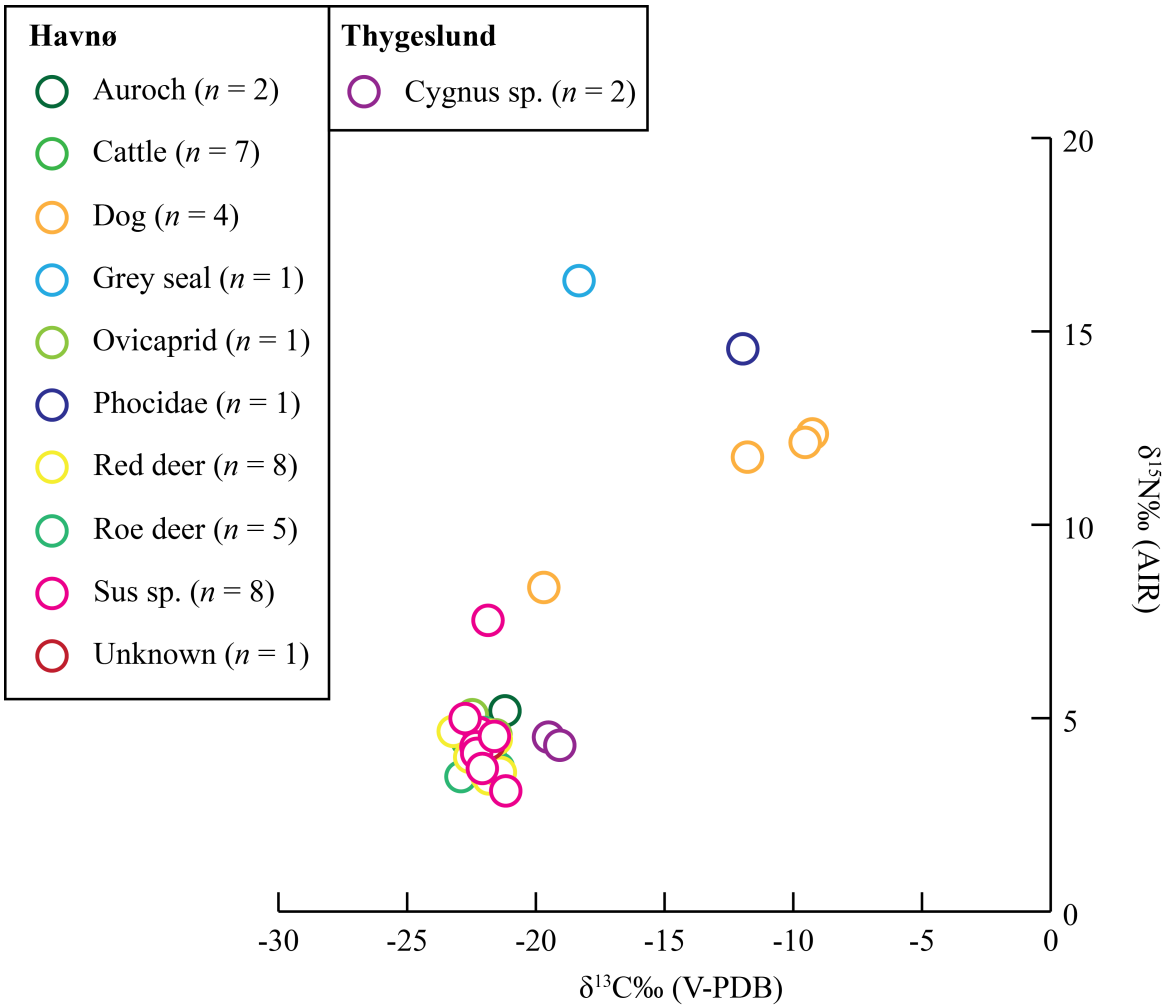


Figure 3.14: Carbon and nitrogen stable isotope data obtained from bird (Thygeslund) and mammalian bone collagen from the Havnø kitchen midden (Gron 2013a).

The results for adult (1) predicted that on the whole marine fish were negligible in the diet (Figures 3.16 and 3.17). In essence the individual had had a diet that was consistent with the consumption of C_3 cereals and C_3 terrestrial mammals in almost equal proportions. The box and whisker plots demonstrated that the C_3 terrestrial mammals had a marginally higher estimated mean and median when compared with the C_3 cereals and marine fish.

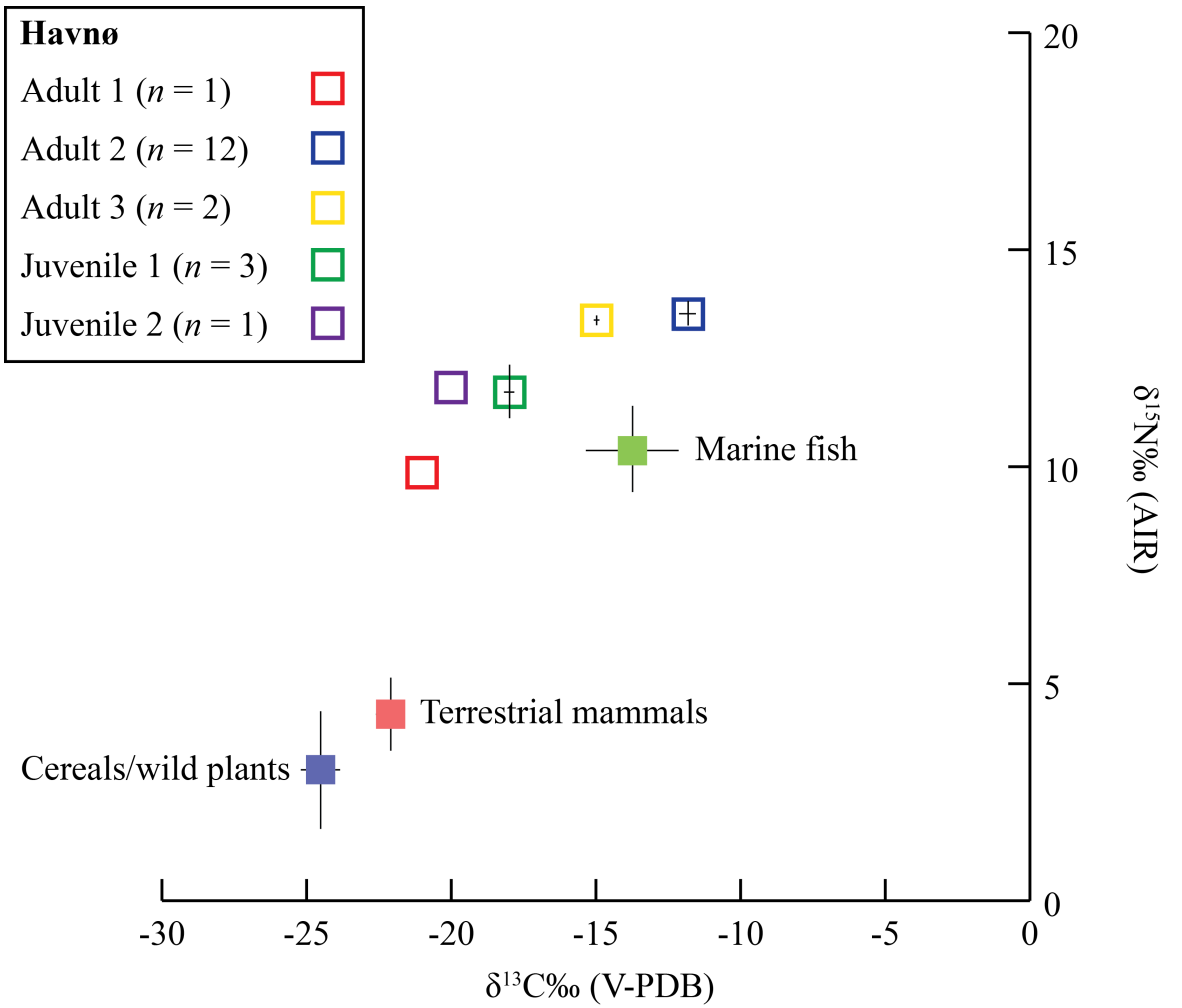
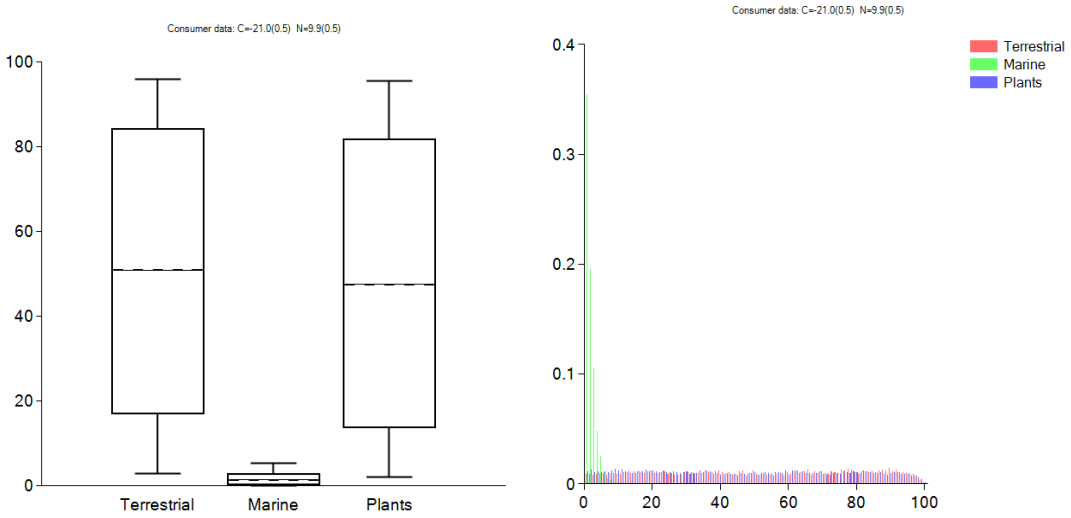


Figure 3.15: Carbon and nitrogen stable isotope data obtained on faunal and human bone collagen from the Havnø kitchen midden. Where applicable, the box and whisker plots for the humans represent the mean and STDVs (± 1σ) obtained from several measurements. The box and whisker plots for the three food groups are also provided: C_3 cereals/wild plants (Bogaard et al. 2013), C_3 terrestrial mammals (Gron 2013a), and marine fish including the eel that has been reproduced from Robson et al. (2012).

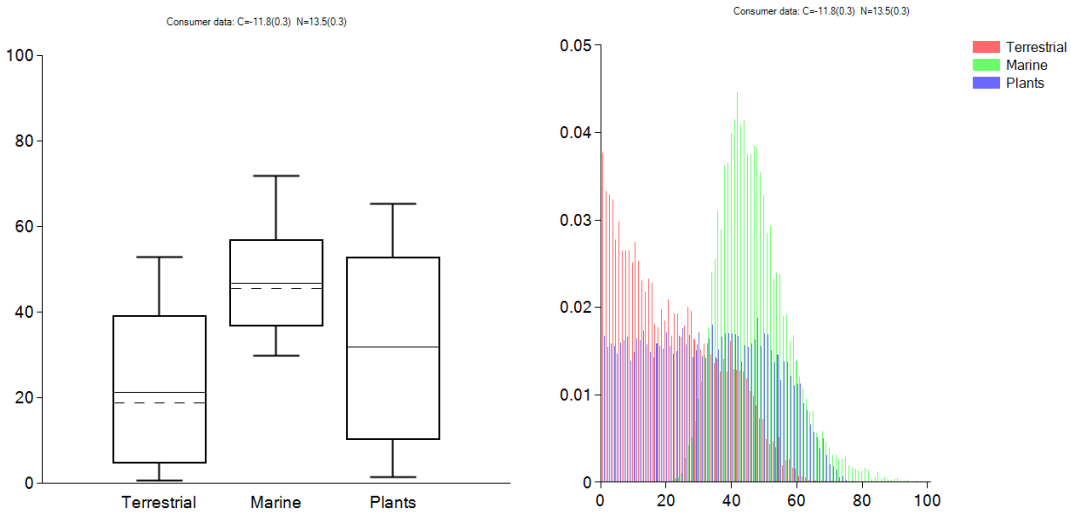
On the other hand adult (2) had had a diet that had been largely composed of marine fish (Figures 3.18 and 3.19). However, there was some mixing present including the consumption of C_3 wild plants and C_3 terrestrial resources. The box and whisker plots demonstrated that the marine fish had a higher mean and median when compared with the C_3 wild plants and C_3 terrestrial mammals.

The results for adult (3) predicted that C_3 wild plants contributed the most toward the diet

(Figures 3.20 and 3.21). In a similar manner to adult (2) marine fish and C_3 terrestrial resources had also been consumed. The results demonstrated that C_3 wild plants had a higher estimated mean and median compared with C_3 terrestrial resources and marine fish.



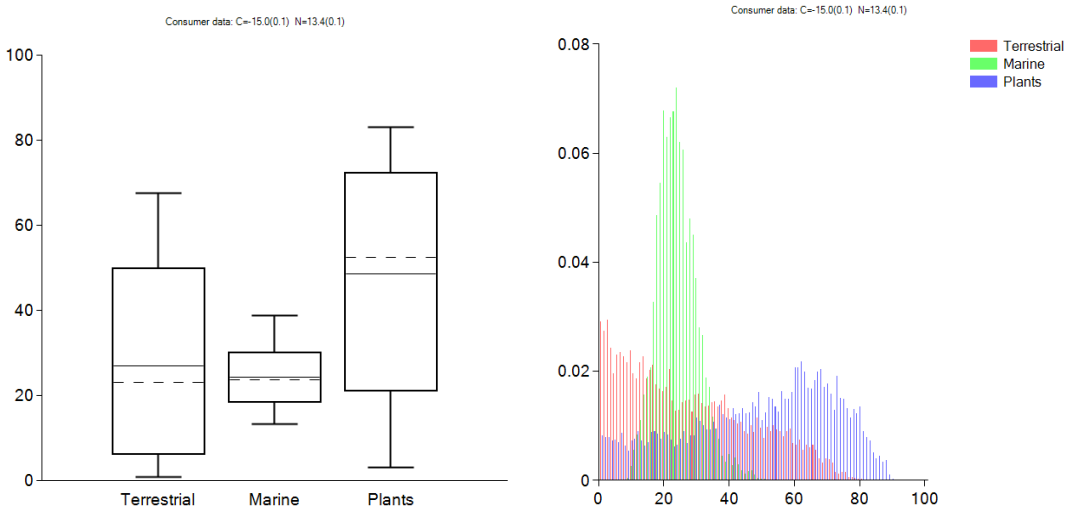
Figures 3.16 and 3.17: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 cereals, C_3 terrestrial mammals, and marine fish food groups for adult (1).



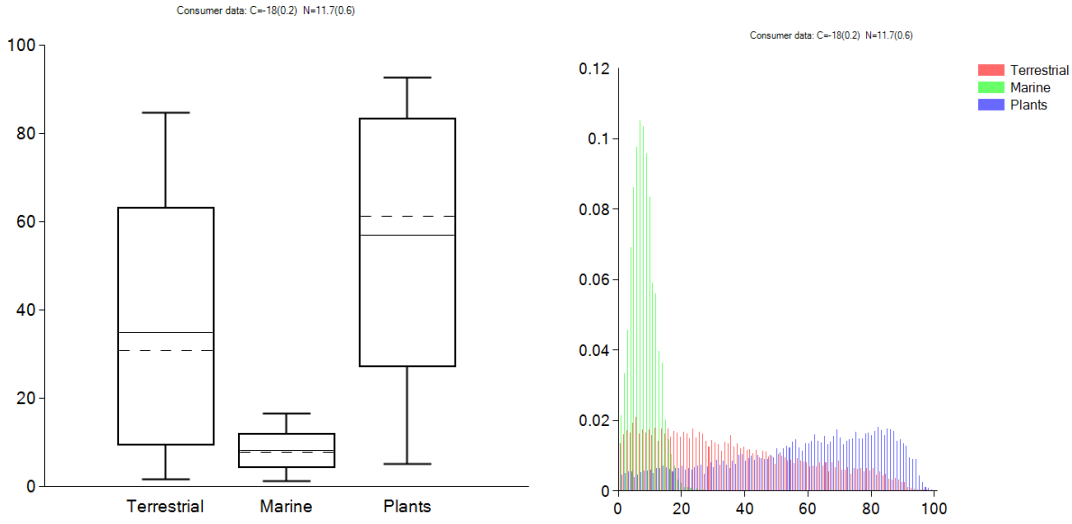
Figures 3:18 and 3.19: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 wild plants, C_3 terrestrial mammals, and marine fish food groups for adult (2).

The results for juvenile (1) predicted that C_3 cereals contributed the most towards the diet

although C_3 terrestrial resources and marine fish had also been consumed (Figures 3.22 and 3.23). The results demonstrated that C_3 cereals had a higher estimated mean and median compared with the C_3 terrestrial resources and marine fish.



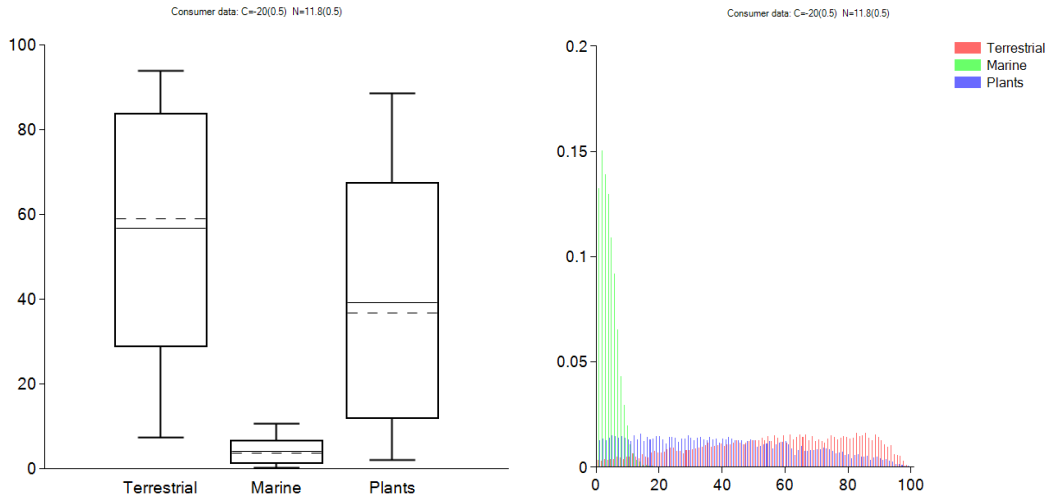
Figures 3.20 and 3.21: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 wild plants, C_3 terrestrial mammals, and marine fish food groups for adult (3).



Figures 3.22 and 3.23: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 cereals, C_3 terrestrial mammals, and marine fish food groups for juvenile (1).

The results for juvenile (2) predicted that C_3 terrestrial resources contributed the most

towards the diet. However it would appear that some mixing had taken place as demonstrated by the overlap (Figures 3.24 and 3.25). The results demonstrated that C_3 terrestrial resources had a higher estimated mean and median compared with C_3 cereals and marine fish.



Figures 3.24 and 3.25: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 cereals, C_3 terrestrial mammals, and marine fish food groups for juvenile (2).

3.7.3. Sulphur stable isotope analysis

In total nine samples were selected for sulphur stable isotope analysis based on collagen yield. Of these, only four produced sufficiently well preserved collagen for accurate isotope measurements, and met the quality criteria proposed by Nehlich and Richards (2009) and Nehlich *et al*. (2013). These data are plotted in Figure 3.26. On the whole it can be seen that there were marked differences in the amount of sulphur, C:S and N:S atomic ratios between the human and roe deer samples, and that sulphur stable isotope analysis is beneficial when the nitrogen data are taken into consideration.

Of the five samples that yielded unreliable data, two of the four fish bone samples had amounts of sulphur that were <0.4 wt. %, while three of the four fish bone samples, and one of the three human bone samples possessed N:S ratios that were outside of the acceptable ranges of 200 ± 100 for bird and mammal bone collagen, and 60 ± 20 for fish bone collagen respectively. All five unreliable samples (four fish and one human) possessed C:S ratios

that were outside the acceptable ranges of 600 ± 300 for bird and mammal bone collagen, and 175 ± 50 for fish bone collagen respectively (Nehlich and Richards 2009; Nehlich *et al*. 2013).

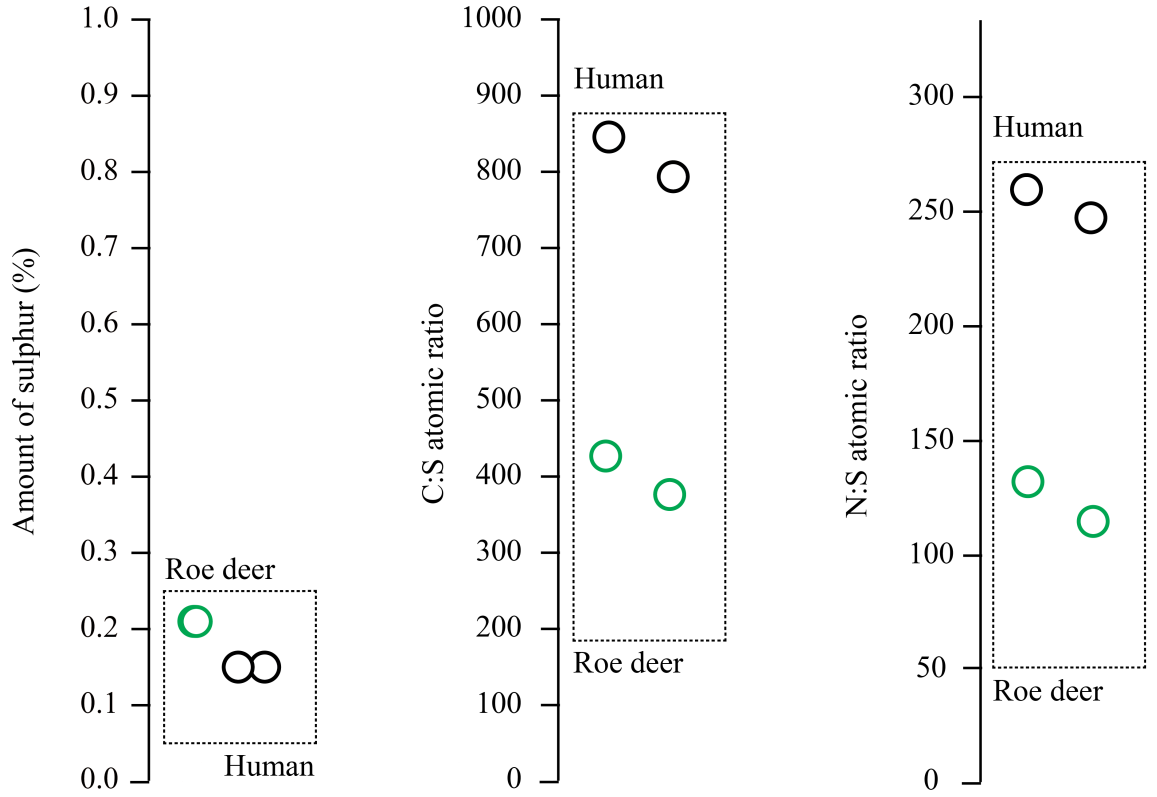


Figure 3.26: (left) Amount of sulphur (%) in bone collagen, (middle) C:S atomic ratio, and (right) N:S atomic ratio obtained from mammal and human bone collagen from the Havnø kitchen midden. The dotted boxes demarcate the established ranges (Nehlich and Richards 2009).

The sulphur stable isotope data are plotted in Figure 3.27. The summary statistics for each category included in this study are shown in Table 3.4. A full listing of the isotope data is provided in Appendix 2.

3.7.3.1. Human remains

The two human bone collagen samples that yielded reliable data were represented by adult (2) and juvenile (1) in the assemblage. Adult (2) possessed a depleted $\delta^{34}S$ value when compared to juvenile (1). A $\delta^{34}S$ value of +8.5‰ was within the range established for freshwater and estuarine birds, fish and terrestrial mammals. On the other hand, juvenile (1)

had a $\delta^{34}S$ value of +14.4‰ that was consistent with sulphur derived from the consumption of resources whose habitat had been influenced by freshwater inputs, that is, an estuarine or coastal environment (Nehlich and Richards 2009; Nehlich *et al*. 2013).

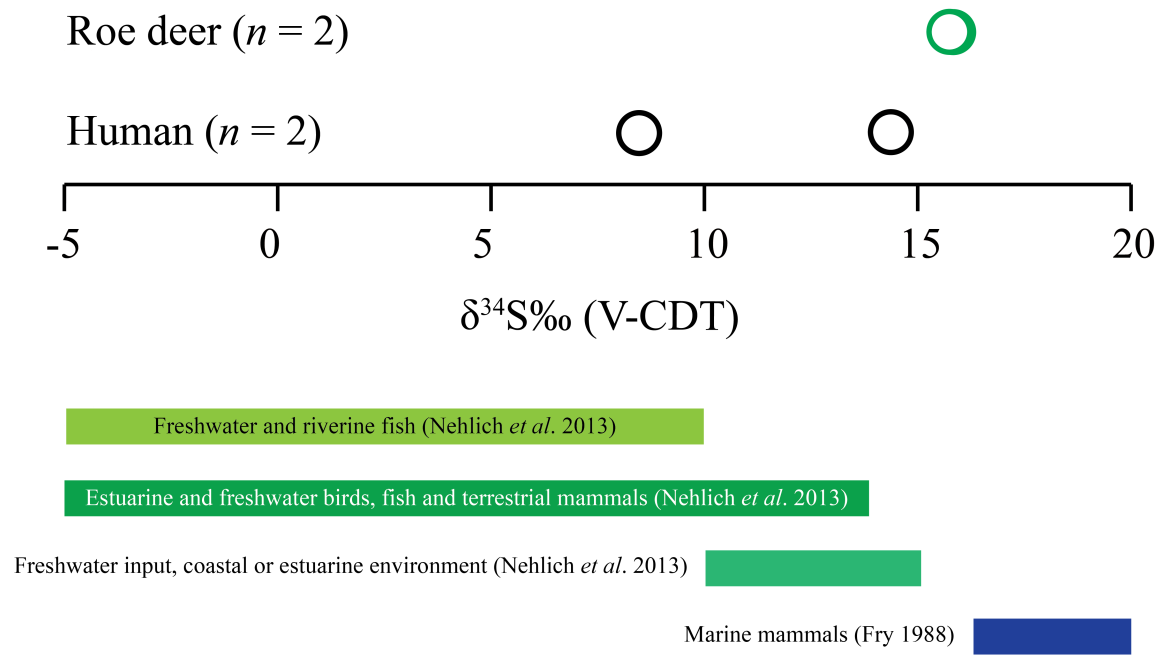


Figure 3.27: Sulphur stable isotope data obtained from human and roe deer bone collagen from the Havnø kitchen midden.

Sample Group	**Sample size**	**Mean $\delta^{34}S_{V\text{-}CDT}$ (‰) ± STDV (± 1σ)**	**Mean $\delta^{13}C_{V\text{-}PDB}$ (‰) ± STDV (± 1σ)**	**Mean $\delta^{15}N_{AIR}$ (‰) ± STDV (± 1σ)**
Mammals - roe deer	2	+15.8 ± 0.1	-22.2 ± 1.0	+3.6 ± 0.2
Humans - all	2	+11.4 ± 4.2	-15.1 ± 4.0	+12.6 ± 1.6
Humans - adult	1	+8.5	-12.3	+13.7
Humans - juvenile	1	+14.4	-18.0	+11.5

Table 3.4: Summary statistics for the four samples that produced sufficiently well preserved collagen for accurate isotope measurements, which also met the quality criteria proposed by Nehlich and Richards (2009) and Nehlich et al. (2013).

3.7.3.2. Mammals

The two roe deer specimens analysed in this study yielded reliable data. While they had a narrow range in their $\delta^{13}C$ and $\delta^{15}N$ values, they possessed identical $\delta^{34}S$ values of +15.8‰. The $\delta^{34}S$ values were marginally below the threshold (+16.0‰) that distinguishes between marine and estuarine environments (Fry 1988). It is more than likely that they had consumed flora that had been affected by marine derived sulphur, which could have been in the form of either precipitation or sea-spray (Craig *et al*. 2006). Overall, the $\delta^{34}S$ values indicated that the roe deer subsisted in an environment that was proximal to the sea (Nehlich and Richards 2009; Nehlich *et al*. 2013; Zazzo *et al*. 2011). Despite the fact that residency in salt marsh environments and sea spray can elevate the nitrogen values, comparison with other contemporaneous deer demonstrated that they are not appreciably different.

3.7.4. AMS radiocarbon dates

Accelerator mass spectrometry radiocarbon dates obtained from a total of 26 samples taken in association with the excavations at the kitchen midden at Havnø are listed in Appendix 2. Based on the Libby half-life, the ^{14}C age was determined in conventional radiocarbon years BP (i.e. before 1950 AD), and the range of calibrated ages corresponding to ±1 standard deviation are reported (see section 3.6.5. Calibration of the AMS radiocarbon dates). The dates are rounded to the nearest 10 years, and are plotted in Figures 3.28 to 3.31.

When these data were collated according to their spatial distribution and level, they demonstrated that the Havnø kitchen midden had been used over a surprisingly long period of time, ca. 2660 radiocarbon years, from ca. 4540-1880 cal BC, that is, the late Mesolithic to the late Neolithic. However, it is highly unlikely that occupation at the kitchen midden was continuous given their extremely complex depositional histories (Andersen 2000a, 2001, 2004a, 2007, 2008a). Moreover, these data probably represent a combination of time averaged as well as single depositional events.

The eastern portion of the midden proper (Figure 3.28) was dated from ca. 3890-3580 cal BC (n = 6), whereas the central part of the midden proper (Figure 3.29) from ca. 4540-1880 cal BC (n = 9). The western portion of the midden proper (Figure 3.30) was dated from ca.

4510-3780 cal BC (n = 3), while the outlying squares to the north of the midden proper (Figure 3.31) from ca. 3980-2400 cal BC (n = 7). On the whole the midden proper was in use from ca. 4540-1880 cal BC, that is, the late Mesolithic through the Neolithic, whereas the rear had been in use from ca. 3980-2360 cal BC, that is, the early Neolithic through the late Neolithic.

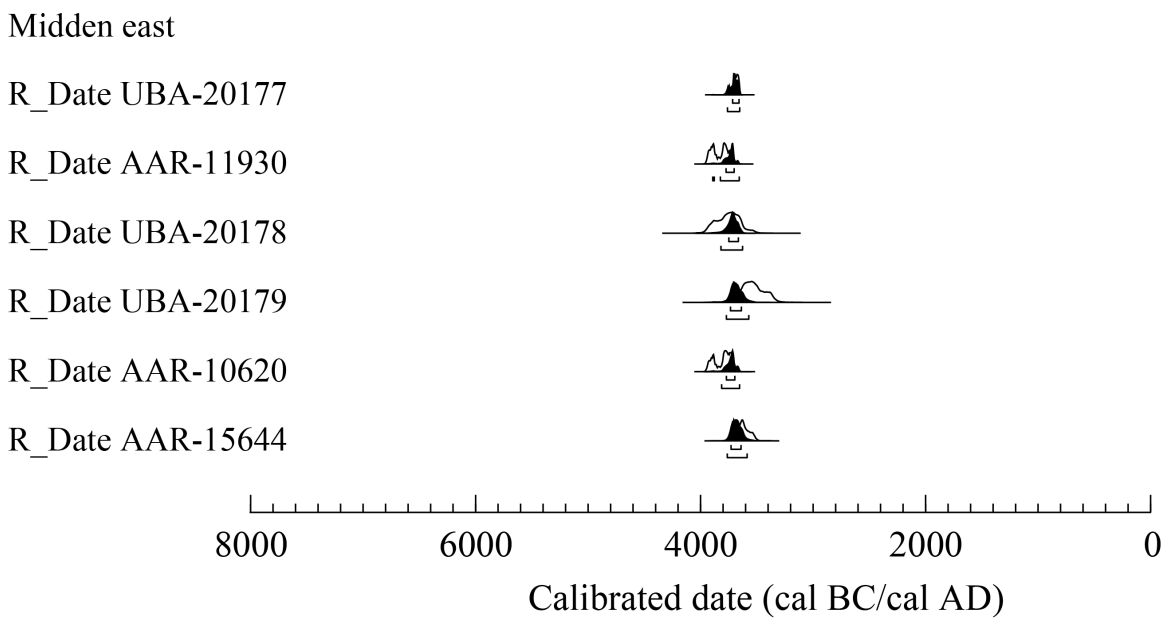


Figure 3.28: Graph of calibrated (1σ) AMS radiocarbon C-14 dates for the eastern portion of the midden proper.

3.7.4.1. Human remains

In order to determine the relative age of the individuals, five human remains were AMS radiocarbon dated. These data are listed in Table 3.5. It can be seen that adult (1) was dated to the SGC-PWC cultures, whereas adult (2), represented by two dates, was dated to the EBK-TRB transition. Juvenile (1) similarly was dated to the SGC-PWC cultures, whereas juvenile (2) was dated to the TRB. On the whole these data confirmed that the observed dietary change coincided with the Mesolithic-Neolithic transition. In addition, these data demonstrated that there were at least three different depositional events of human remains at the kitchen midden.

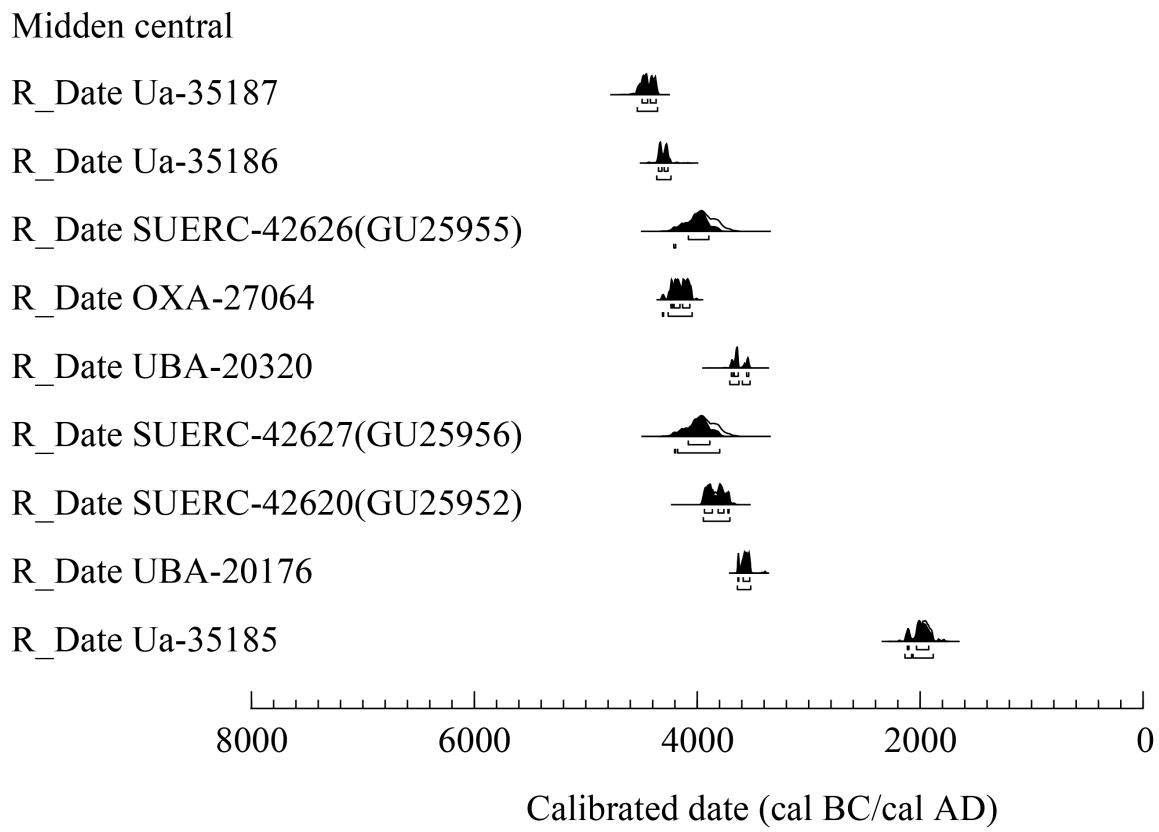


Figure 3.29: Graph of calibrated (1σ) AMS radiocarbon C-14 dates for the midden proper.

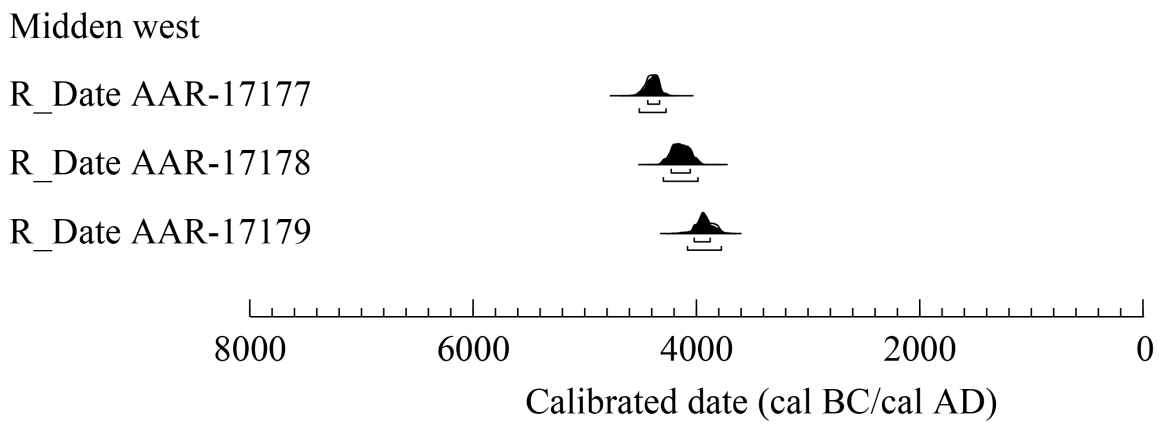


Figure 3.30: Graph of calibrated (1σ) AMS radiocarbon C-14 dates for the western portion of the midden proper.

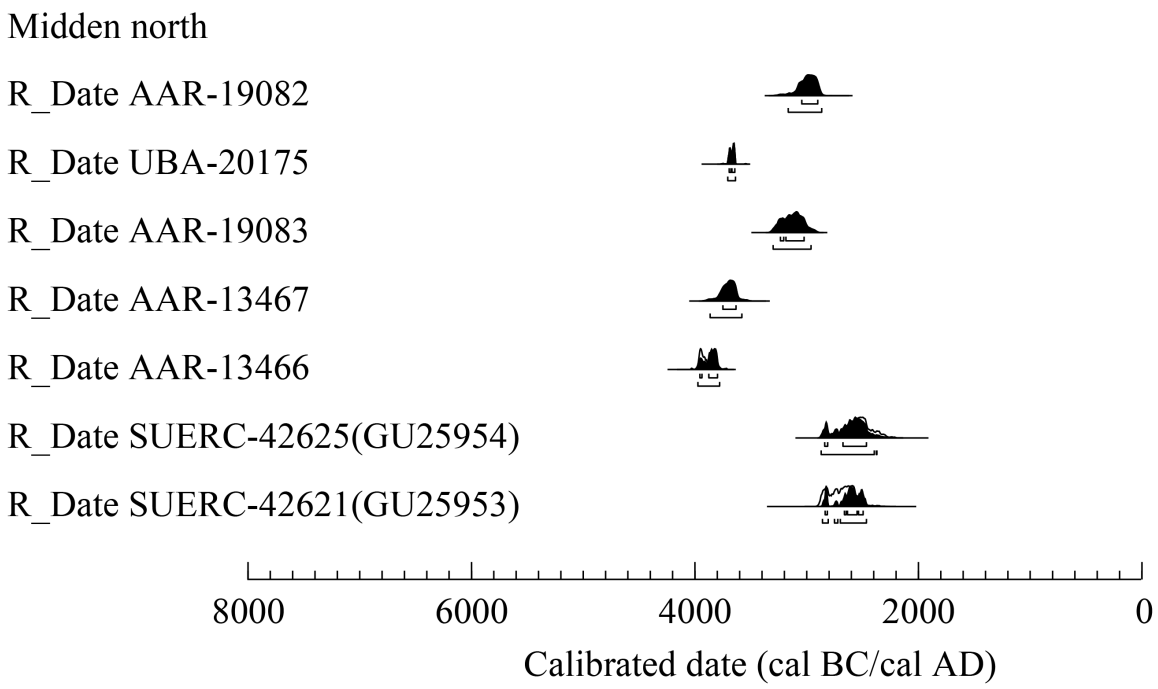


Figure 3.31: Graph of calibrated (1σ) AMS radiocarbon C-14 dates for the outlying squares to the north of the midden proper.

Individual	**Lab no.**	**Radiocarbon age**	**Calibrated age at ± 1 sigma**
		BP	**BC**
Adult (1)	SUERC-42621 (GU25953)	4101 ± 29	2860-2470
Adult (2)	SUERC-42626 (GU25955)	5880 ± 29	4210-3810
Adult (2)	SUERC-42627 (GU25956)	5869 ± 29	4210-3800
Juvenile (1)	SUERC-42625 (GU25954)	4233 ± 29	2870-2400
Juvenile (2)	SUERC-42620 (GU25952)	5067 ± 29	3950-3710

Table 3.5: Table to show the recalibrated AMS C-14 radiocarbon dates measured on the five human remains from the kitchen midden.

3.8. Discussion

3.8.1. Carbon and nitrogen stable isotope analyses

3.8.1.1. Collagen preservation

For inter-site comparison, four human remains were analysed from the EBK kitchen midden at Holmegård. Thus, a total of 46 samples were analysed in this study. Of these, 43 (93.5%) yield reliable data. In comparison, Fischer *et al*. (2007) analysed 203 fish, human and mammal specimens from across a range of different types of site in southern Scandinavia and northern Europe. Of these only 154 were successful (76%).

The data from this study demonstrates an important point, that bone collagen is likely to be better preserved within kitchen middens as opposed to other types of site. The overall high success rate from this study was probably attributable to the calcium carbonate ($CaCO_3$) content of the shells, which buffer against acid hydrolysis of the soluble bone collagen (Noe-Nygaard 1987; Schulting 2011). In all likelihood, the preponderance of mollusc shells are protective of the bone materials deposited within kitchen midden, and prevents the acid dissolution of the mineral component of the bone as well as water percolation through the midden sequence (Noe-Nygaard 1987). Moreover, Schmölcke *et al*. (2015) recently reported a success rate of 100% for carbon and nitrogen stable isotope analysis of fish bone collagen from the freshwater shell midden at Riņņukalns, Latvia.

3.8.1.2. The human remains from Havnø

The osteological analysis undertaken by Hellwell (2012a) calculated a MNI of three human individuals in the Havnø assemblage. However it was only possible to sample two of these individuals since one remains housed at the Zoological Museum in Copenhagen. The carbon and nitrogen stable isotope analysis undertaken in this study confirmed that there were at the very least six individuals deposited at the kitchen midden: one adolescent, three adults, and two juveniles. Thus, the study stresses an important methodological point. That stable isotope analysis should be undertaken alongside the osteological analysis of human remains particularly when an assemblage is highly fragmented, and the reconstruction of MNI is problematic.

Based on the carbon and nitrogen stable isotope analysis alone, the five human individuals analysed from Havnø appeared to be no exception to the previously identified dietary change. Adult (2) that was dated to the late Mesolithic had a diet that was consistent with

the long-term consumption of marine derived protein, whereas adult (1) as well as juveniles (1) and (2) that were dated to the Neolithic appeared to have consumed terrestrial derived protein. However, these data indicated that some aquatic derived protein had been consumed during the Neolithic, and were similar to a number of TRB individuals that had depleted $\delta^{13}C$ values and elevated $\delta^{15}N$ values in the study by Fischer *et al*. (2007). At the present adult (3) remains undated although it is likely to represent another Mesolithic individual at the kitchen midden given its location within the kitchen midden as well as the stable isotope data that is similar when compared with other dated EBK individuals in Denmark. The individual had an intermediary $\delta^{13}C$ value between the marine and terrestrial endpoints (Fischer *et al*. 2007). Despite the proposed mechanisms for the transition to domesticated fauna and flora (Chapter 1), the results from this study either demonstrated a dietary change among the residents interred at the kitchen midden, or represent a replacement group of inhabitants with their own, uniquely different diet at the same locality.

Overall the data obtained in this study are consistent with a gradual decline in the long-term consumption of marine derived protein when agricultural and domesticated products became more readily available (Tauber 1981; Noe-Nygaard 1988). It is more than likely that the Neolithic individuals interred at the kitchen midden consumed a combination of aquatic (freshwater and marine) and terrestrial derived protein, and not as Tauber's (1981) suggestion – the substitution of high trophic level marine resources with domesticated fauna and flora. In support of the above, at least 135 (NISP) freshwater fish remains have been identified in the assemblage from Havnø (Chapter 6). Likewise freshwater fish and molluscs are known from numerous TRB sites in the Åmose bog complex on Zealand (Fischer and Heinemeier 2003; Koch 1998; Noe-Nygaard 1995; Skaarup 1973).

3.8.1.3. Human remains from the Holmegård kitchen midden

For inter-site comparison, carbon and nitrogen stable isotope analysis was undertaken on four human remains recovered from the Holmegård kitchen midden (Figure 3.32). Of the four specimens analysed, two are derived from the inhumation burial of a young adult male that was dated to the EBK (Chapter 2), whereas the remainder were recovered from within

the kitchen midden matrices, ca. 2-3 m away (Andersen personal communication 2014). These data are plotted in Figure 3.33.

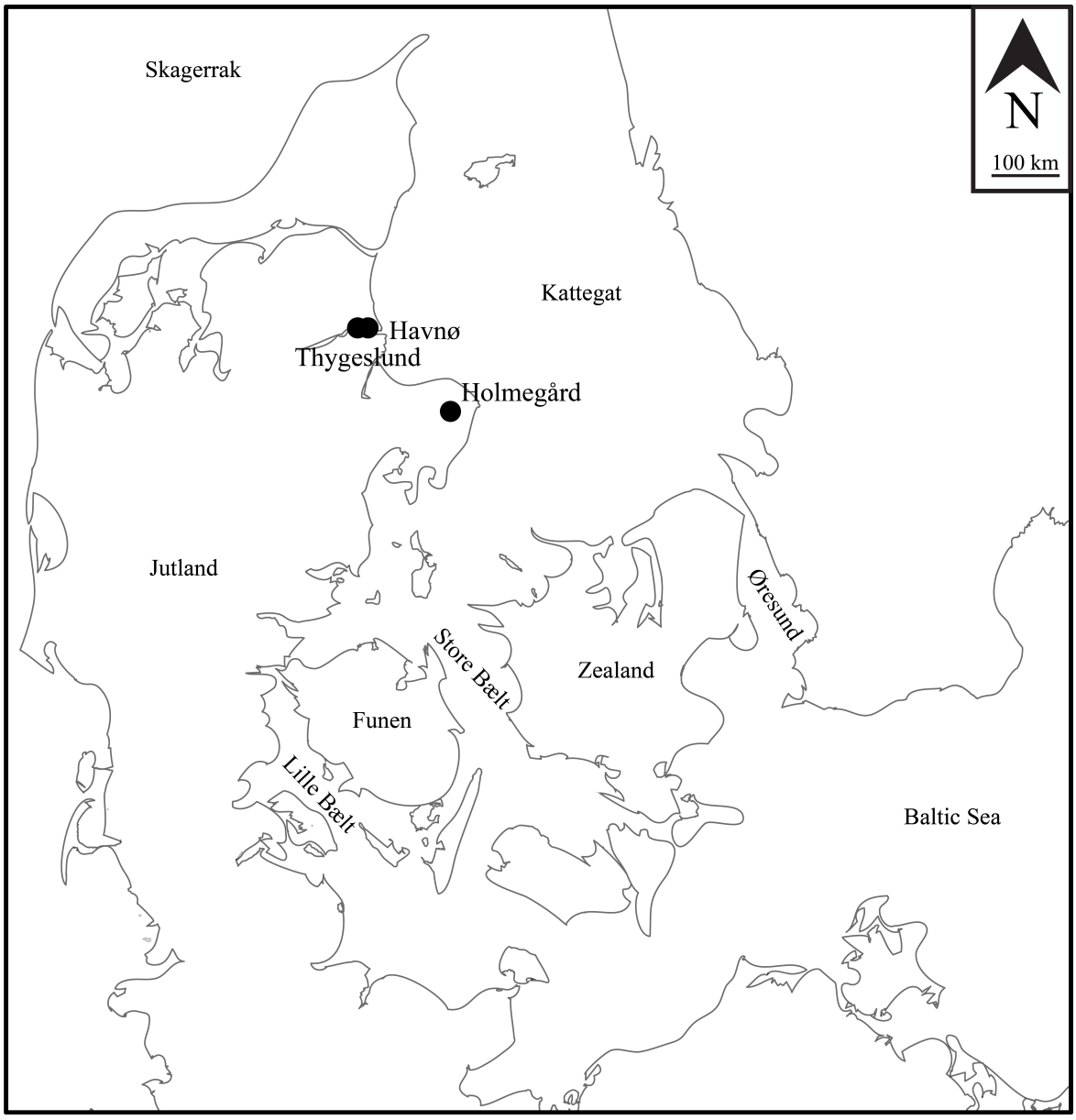


Figure 3.32: Map of Denmark showing the locations of the sites that were sampled in the study for stable isotope analyses.

The loose human remains had $\delta^{13}C$ and $\delta^{15}N$ values consistent with the two elements sampled from the inhumation burial. Thus, they are probably derived from the young adult male given the ranges in their $\delta^{13}C$ and $\delta^{15}N$ values that were of the order of ± 1‰ (DeNiro

and Schoeniger 1983; Pestle *et al*. 2014). These data (Table 3.6) were comparable with those obtained from the five individuals sampled from Havnø. For instance, adult two from Havnø had a small range in the standard deviations for the $\delta^{13}C$ (± 0.1‰ to ± 0.3‰) and $\delta^{15}N$ (± 0.1‰ to ± 0.6‰). This variability was probably attributable to: (1) multiple measurements on skeletal elements deriving from adult two, and (2) a reflection of differing protein turnover rates of the different skeletal elements.

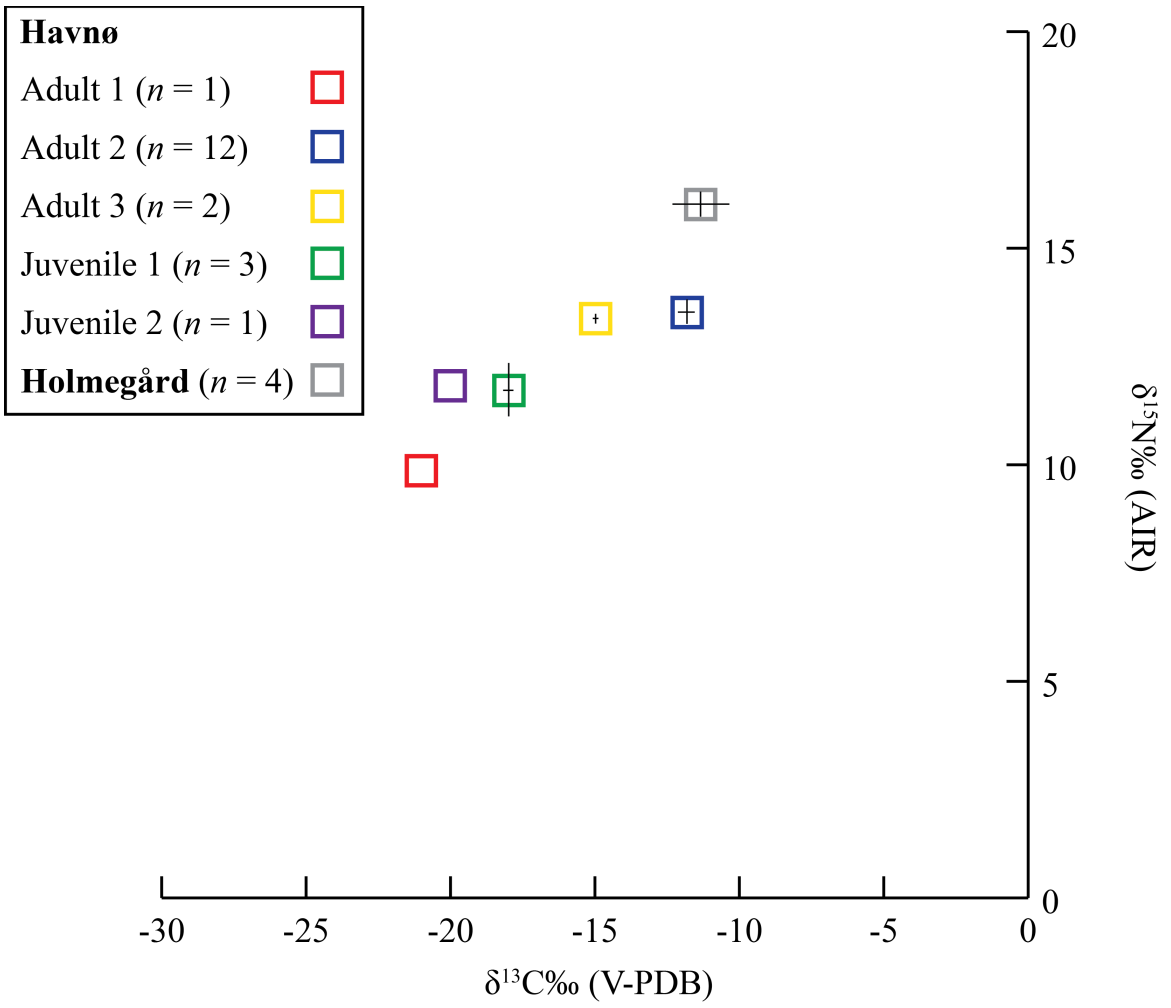


Figure 3.33: Carbon and nitrogen isotope data from human bone collagen from the Havnø and Holmegård kitchen middens.

In comparison with adult two from Havnø, the adult had a similar $\delta^{13}C$ value. Despite previous AMS radiocarbon dating (Gillespie *et al*. 1984; Andersen *et al*. 1986), the $\delta^{15}N$ values were not measured in either study. Thus, the individual's position in the food chain

remained unknown. In comparison with the five individuals from Havnø, the Holmegård individual had a slightly elevated $\delta^{15}N$ value. On the whole these data demonstrated the long-term consumption of marine derived protein, and of resources that were higher up in the trophic level hierarchy.

Sample Group	Sample size	$\delta^{13}C_{V\text{-}PDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)
Holmegård			
Humans - all	4	-11.4 ± 1.0	16.0 ± 0.3
Humans - burial	2	-11.7 ± 1.5	15.8 ± 0.4
Humans - loose	2	-11.2 ± 0.6	16.1 ± 0.0

Table 3.6: Summary statistics for the sampled human remains from the Holmegård kitchen midden.

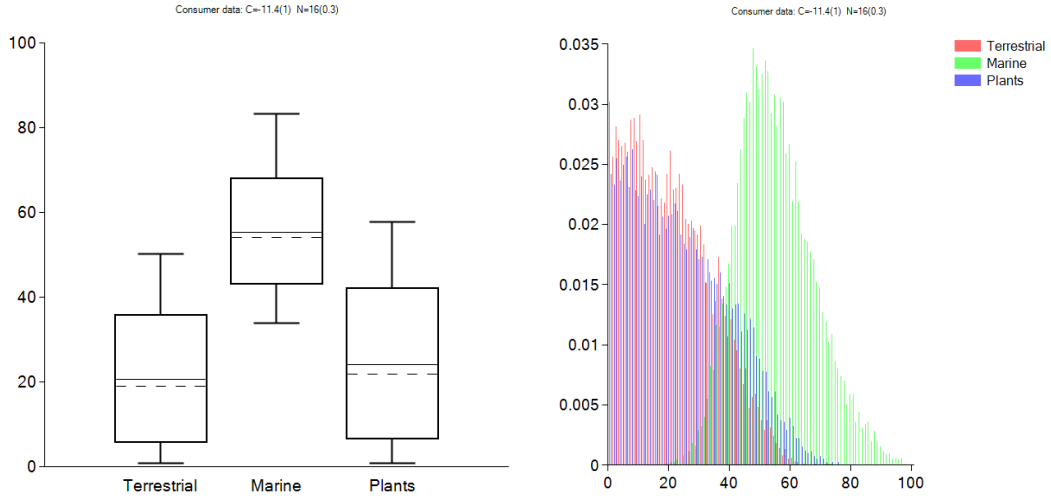
For comparison, FRUITS was used to predict the whole diet of the EBK adult interred at Holmegård. The assumed scenario was identical to that applied to the individuals from Havnø. In a similar manner to adult (2) from Havnø it can be seen that the Holmegård adult had had a diet that had been largely composed of marine fish (Figures 3.34 and 3.35). Equally, some mixing was present including the consumption of C_3 wild plants and C_3 terrestrial resources. The box and whisker plots demonstrated that the marine fish had a higher mean and median when compared with the C_3 wild plants and C_3 terrestrial mammals.

3.8.1.4. Comparison with published stable isotope data

The carbon and nitrogen stable isotope data from the human individuals from Havnø and Holmegård are compared with previously published values obtained from human bone collagen. These data are derived from coastal and inland Danish archaeological sites dating to the EBK and TRB. A full listing of these data can be found in Appendix 2.

Although Denmark has one of the largest assemblages of human remains dating to the late Mesolithic and early Neolithic when compared with the majority of other regions throughout Europe (Schulting 2010), previous studies had not always measured both the $\delta^{13}C$ and $\delta^{15}N$ values. In total, the data available in the literature amounts to 101 EBK, TRB and transitional human bone collagen samples. Of these, some are represented by multiple analyses undertaken on the same specimen. Thus, only 62 data are available for comparison

since one individual from Tybrind Vig had a C:N atomic ratio of 3.7 (Fischer *et al*. 2007), and as such has been excluded. Figure 3.36 plots these data. Briefly, 17 are derived from coastal and inland EBK sites, whereas 43 were sampled from coastal and inland TRB localities. In addition, the three samples that were not assigned to cultural epoch were included, and represented one coastal and inland site respectively.



Figures 3.34 and 3.35: Box and whisker plots (left) and probability distributions (right) of the dietary intakes of C_3 wild plants, C_3 terrestrial mammals, and marine fish food groups for the adult burial from the Holmegård kitchen midden.

Overall the dataset demonstrates that the Mesolithic and Neolithic individuals recovered from Havnø and Holmegård had diets consistent with individuals recovered from contemporaneous coastal and inland localities throughout Denmark. Adult one (TRB) from Havnø had considerable overlap with the majority of the human individuals that are derived from inland localities. These data indicated that the long-term diet of these individuals was consistent with the consumption of terrestrial derived protein. This is particularly interesting because it could represent an individual that had resided in the hinterland but had been intentionally deposited at the kitchen midden. Adult two (EBK) plotted alongside several of the EBK humans recovered from coastal sites, and reinforces the notion for the consumption of aquatic derived protein during this period. Adult three, which remains undated (presumed EBK-TRB), similarly plotted with the humans sampled from other coastal EBK sites as well as the one individual sampled from Bodal K (Fischer *et al*. 2007).

From a cursory point of view, these intermediary values probably represent the consumption of both marine and terrestrial derived protein. On the other hand, the two juveniles dated to the TRB and SGC-DC plotted slightly above the majority of the coastal and inland TRB individuals' sampled. It can be seen that these data plot alongside specimens recovered from coastal (Pandebjerg) and inland (Boelkilde) locations. These individuals probably consumed a combination of freshwater, marine, and terrestrial derived protein.

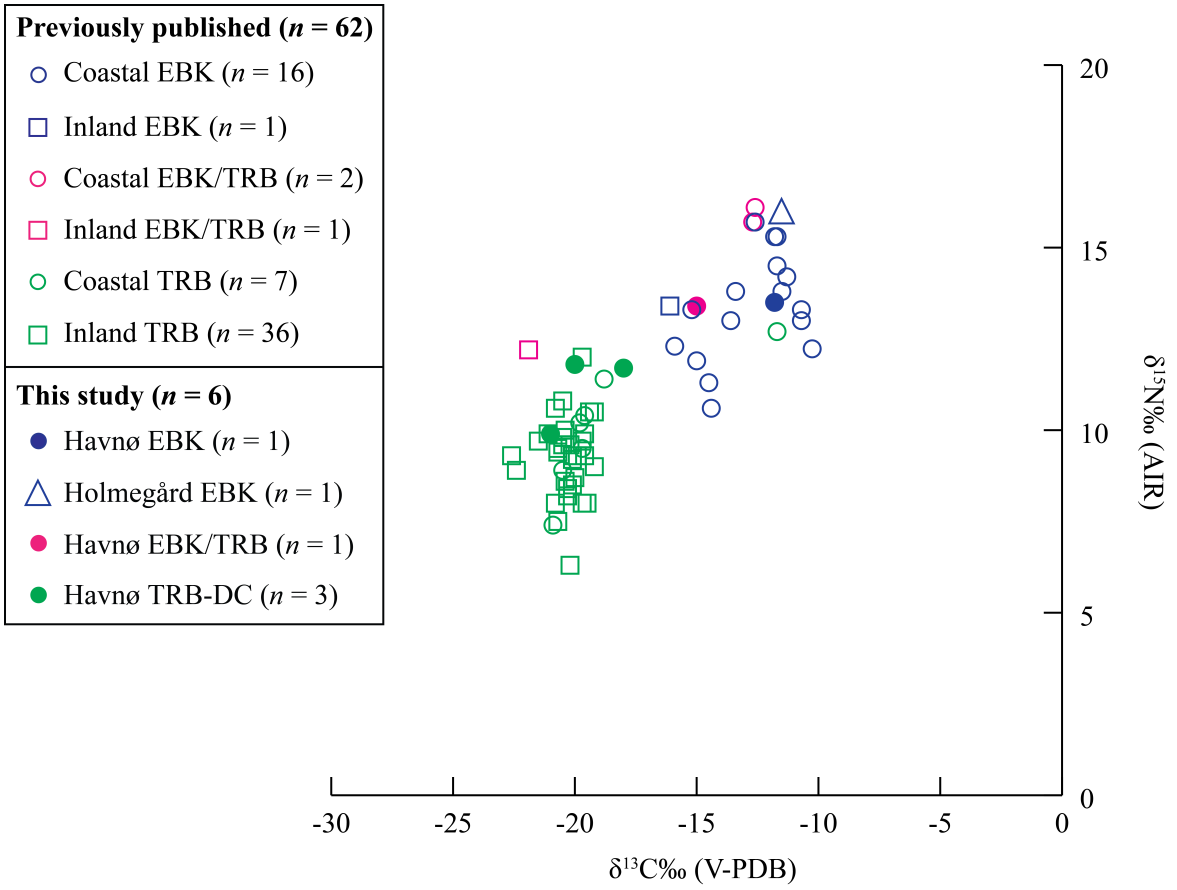


Figure 3.36: Carbon and nitrogen isotope data obtained from human bone collagen from the Havnø and Holmegård kitchen middens compared with previously published data that is listed in Appendix 2.

Interestingly the individual from Holmegård had one of the most elevated $\delta^{15}N$ values within the dataset. The adult had a mean $\delta^{15}N$ value of +16.0‰ that was similar with the individual interred in a dugout canoe from the submerged site at Møllegabet (+15.7‰), as well as the loose human remains sampled from the Norsminde and Vængesø I kitchen

middens (both +15.3‰), and the male and female inhumation burials from the Vængesø II kitchen midden (+15.7‰ and +16.1‰ respectively). Since Holmegård, Vængesø I and Vængesø II are situated on the Djursland peninsula, the appreciable difference may be a reflection of the sites' situation, which at the time of material deposition would have been located further out into the Kattegat. Nonetheless despite the fact that these individuals had been deposited at the three kitchen middens, conceivably they could have derived from elsewhere. Notwithstanding the above, these locations may have provided more opportunity, and greater accessibility to marine derived protein from taxa higher up in the trophic level hierarchy. To support this assumption, numerous seals (harp seal and grey seal), and a variety of whales (white-beaked dolphin, killer whale, sperm whale and porpoise) have been identified in the faunal assemblage from the coeval kitchen midden at Vængesø III that is located in the immediate locality (Enghoff 2011).

3.8.1.5. Dietary change at the kitchen middens-fact or fiction?

Ever since the seminal publication by Tauber (1981) there have been several studies on the dietary reconstruction of human remains dating to the Mesolithic and Neolithic periods in Denmark. With the exception of the data derived from the Rødhals kitchen midden, every study has argued for a dietary change across the Mesolithic-Neolithic transition (Clutton-Brock and Noe-Nygaard 1990; Fischer *et al*. 2007; Noe-Nygaard 1988). Overall, the data have demonstrated to the authors that the Mesolithic human individuals had a long-term diet that was principally composed of marine derived protein, whereas the Neolithic human individuals had a long-term diet that was chiefly composed of terrestrial derived protein. However, to a degree these data are not comparable. Firstly, the early Neolithic dataset is overrepresented by human remains derived from inland localities (Fischer *et al*. 2007). Secondly, these data are always plotted with those derived from coastal localities to assess the degree of temporal change without taking into consideration intra-site and inter-site variability. Thirdly, despite the remarkable numbers of stratified kitchen middens there is, in general, a dearth of human remains that have been analysed.

The current stable isotope dataset on human remains derived from kitchen middens totals 11 (Table 3.7). These data are represented by eight kitchen middens, and not one

encompassed human remains from either side of the Mesolithic-Neolithic transition. It is for these reasons why the present study on the one kitchen midden is the more important, and stresses the need for additional research on similar sites.

EBK	**TRB**
Dyrholm (*n* = 1)	Bjørnsholm (*n* = 3)
Ertebølle (*n* = 1)	Rødhals (*n* = 1)
Norsminde (*n* = 1)	Kassemose (*n* = 1)
Vængesø I (*n* = 1)	**Total = 5**
Vængesø II (*n* = 2)	
Total = 6	

Table 3.7: Previously analysed human remains from Danish kitchen middens.

When these data are plotted alongside the data obtained in this study (Figure 3.37) it can be seen that adult (2), the EBK individual from Havnø, plotted with the EBK individual from Dyrholm as well as the TRB individual from Rødhals. In comparison, adult (1), the TRB individual from Havnø, had a slightly depleted $\delta^{15}N$ value when compared to juveniles (1) and (2) as well as the three individuals sampled from Bjørnsholm, and one from Kassemose. Interestingly, adult (3) from Havnø produced almost identical stable isotope data to the 1895 burial from the Ertebølle kitchen midden. On the other hand, juveniles (1) and (2) plotted slightly above the Bjørnsholm and Kassemose individuals. As mentioned above, the Holmegård individual plotted with the double burial from Vængesø II as well as an individual from the nearby Vængesø I kitchen midden and one individual from Norsminde that is obscured. Based on these data alone it can be seen that there is a dietary change, however, it is unclear at best, and not as previously acknowledged, rapid (Tauber 1981). Despite the small sample size, the Neolithic individuals from Bjørnsholm, Havnø and Kassemose indicated a long-term diet that was composed of terrestrial derived protein, which was supplemented with varying quantities of aquatic derived protein as indicated by the slightly elevated $\delta^{13}C$ and $\delta^{15}N$ values. Overall it is not possible to accurately reconstruct the overall diet for the consumers based on these data alone. It was for this reason why FRUITS was undertaken.

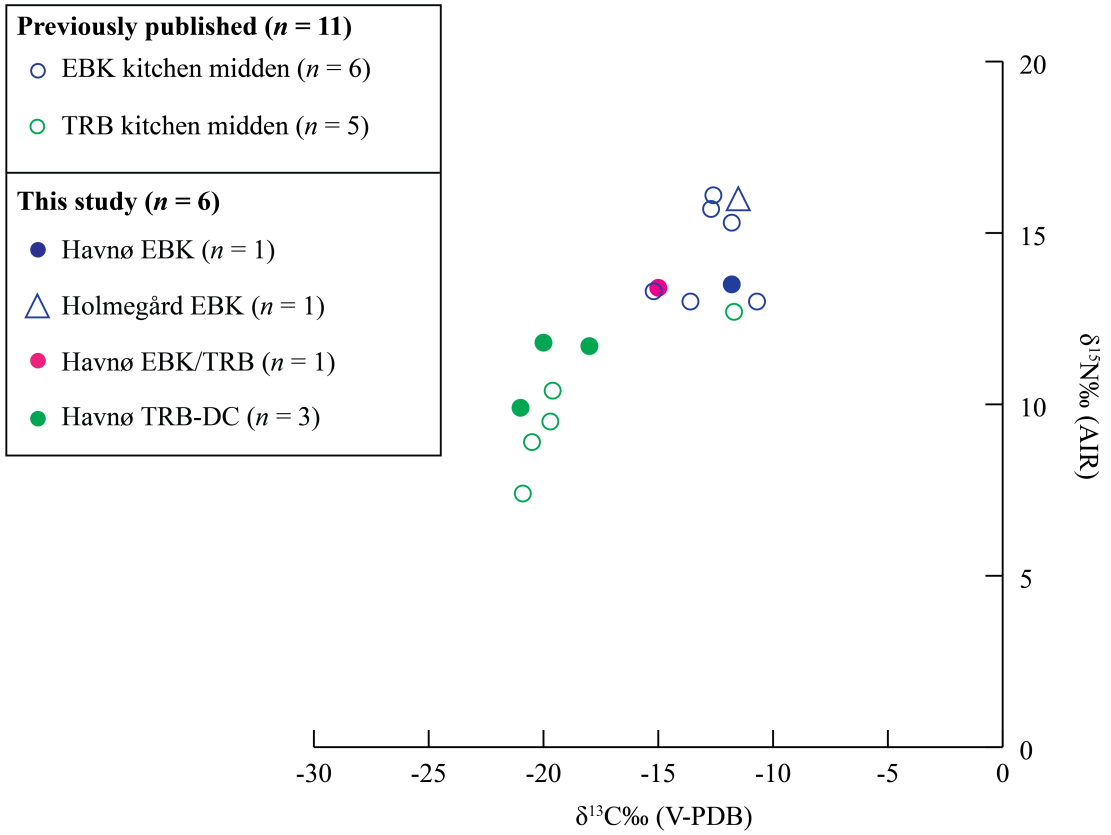


Figure 3.37: Carbon and nitrogen isotope data obtained from human bone collagen from the Havnø and Holmegård kitchen middens compared with previously published data derived from sampled kitchen middens (Fischer et al. 2007).

3.8.1.6. Animal management strategies

On the whole, the terrestrial mammal remains from Havnø had considerable overlap in both their $\delta^{13}C$ and $\delta^{15}N$ values. In comparison with previously published data obtained on 68 specimens from Denmark (Craig *et al*. 2006; Fischer *et al*. 2007; Gron 2013a; Noe-Nygaard *et al*. 2005; Price *et al*. 2007), it is apparent that the domesticated and wild taxa recovered from Havnø had $\delta^{13}C$ and $\delta^{15}N$ values consistent with C_3 terrestrial mammals (Table 3.8).

Previously several studies have been undertaken on bone collagen obtained from aurochs, domestic cattle, red deer and roe deer in order to assess the diet for the earliest cattle in Denmark (Noe-Nygaard 1995; Noe-Nygaard *et al*. 2005; Noe-Nygaard and Hede 2006; Price and Noe-Nygaard 2009). For comparison, 26 TRB cattle were analysed from

throughout Denmark, the majority recovered from archaeological sites in Zealand. Moreover, several specimens were derived from the contemporaneous and nearby kitchen midden at Visborg, located <5 km from Havnø. Since the majority of the samples derived from Zealand, they were compared with the specimens from the peat bog complex, Åmose. It was concluded that there was little or no overlap in the $\delta^{13}C$ and $\delta^{15}N$ values between the earliest domesticated mammals and the wild terrestrial herbivores. Noe-Nygaard *et al*. (2005) argued that there was probably neither a common feeding location nor practices between the two groups. From the beginning of the Neolithic it was argued that the cattle were being kept outside of the forest environments, probably residing and subsisting on coastal plains, and they were not being leaf foddered. While Rasmussen (1989) stated that the early Neolithic humans of southern Scandinavia probably used the latter strategy, there remains a lack of firm archaeological evidence (Noe-Nygaard *et al*. 2005). In comparison, the TRB cattle recovered from Havnø (Gron 2013a) had broadly similar stable isotope data. In contrast, the red and roe deer had more enriched $\delta^{13}C$ values than those recovered from the Åmose (Noe-Nygaard 1995; Noe-Nygaard *et al*. 2005). Therefore it is unlikely that there was a specific feeding strategy in which the early domesticates had been purposefully fed either in a forest environment or left foddered (Gron 2013a). In addition, the data suggested to Gron (2013a) that the TRB red and roe deer from Havnø had been residing and subsisting in more open environments compared to those on Zealand, for instance one that had been previously cleared for either agricultural purposes or forest management or one that had been altered by a rise in sea level (Gron 2013a). On the other hand, the domesticated cattle appear to have been reared locally, for example an open coastal plain, and one that was identical in which the wild terrestrial mammals had been residing in (Gron 2013a). Despite the fact that not all of the specimens in his study could be dated to cultural epoch (Gron 2013a), it was suggested that there appeared to be no discernible dietary change between the late Mesolithic and the early Neolithic mammals deposited at the kitchen midden.

In general, there are only a few studies that have been undertaken on bone collagen obtained from swine dating to the Danish EBK and TRB (Craig *et al*. 2006; Gron 2013a; Noe-Nygaard 1995). In the study by Noe-Nygaard (1995), Mesolithic wild boar were

analysed. Since the $\delta^{13}C$ values were enriched relative to the contemporaneous wild terrestrial herbivores, omnivory was posited. In support of the above, wild boar are known to feed on wild plants, fauna such as carrion, small prey and invertebrates (Genov 1981; Noe-Nygaard 1995; Richter and Noe-Nygaard 2003). However, since the $\delta^{15}N$ values were not reported there is no way of knowing how omnivory affected this isotope. Regarding the swine at Havnø the data were interpreted by Gron (2013a) as either one of the following: (1) the specimens that clustered with the terrestrial herbivores were wild boar, and thus any degree of omnivory is insignificant. If this was the case, the one outlier with an elevated $\delta^{15}N$ value of 7.5‰ (PUD) may have derived from a domestic swine. (2) Overall the swine are largely domesticated, and the one outlier is a wild boar. If this scenario had taken place then the domesticated swine may have been penned, which would have resulted in little omnivory. For comparison, specimen PUD had broadly similar stable isotope data to those derived from an individual of unknown date sampled from the contemporaneous Bjørnsholm kitchen midden (Craig *et al*. 2006). Based on these data Gron (2013a) suggested that the first interpretation was the more plausible. It seems more than likely that the clear separation between groups represents wild versus domestic swine, and despite the small sample size, the difference is present amongst other specimens throughout Denmark (Craig *et al*. 2006).

Location	**Sample size**	**$\delta^{13}C_{V\text{-}PDB}$ (‰)**	**$\delta^{15}N_{AIR}$ (‰)**
Havnø	32	-22.0 ± 0.5	4.3 ± 0.8
Jutland	20	-22.2 ± 1.4	4.6 ± 1.2
Zealand	48	-22.1 ± 0.8	4.9 ± 0.7

Table 3.8: Summary statistics for the domesticated and wild terrestrial taxa from Havnø compared with previously published data obtained on 68 specimens from Denmark.

Based on provenance data alone specimen PUD is dated to the TRB. Thus, if it had been domestic it is likely to have scavenged around the kitchen midden, consuming at least, in part, agricultural food waste and human faeces (Rowley-Conwy *et al*. 2012). Conceivably the consumption of aquatic derived protein can be envisaged to the exclusion of agricultural food waste. However, these data do not tally with three of the four domesticated dogs (Gron 2013a) that consumed marine derived protein, and plotted alongside the flatfish and

slightly above the eel (Figure 3.38). The most likely interpretation is that the specimen resided in the hinterland during the TRB, where it was slaughtered and butchered. Subsequently body parts were transported to the island alongside other domesticates (Gron 2013a), freshwater fish (Chapter 6) and molluscs (Demarchi personal communication 2015). This presumption is supported by similar data elsewhere (Matsui *et al*. 2005; Minagawa *et al*. 2005).

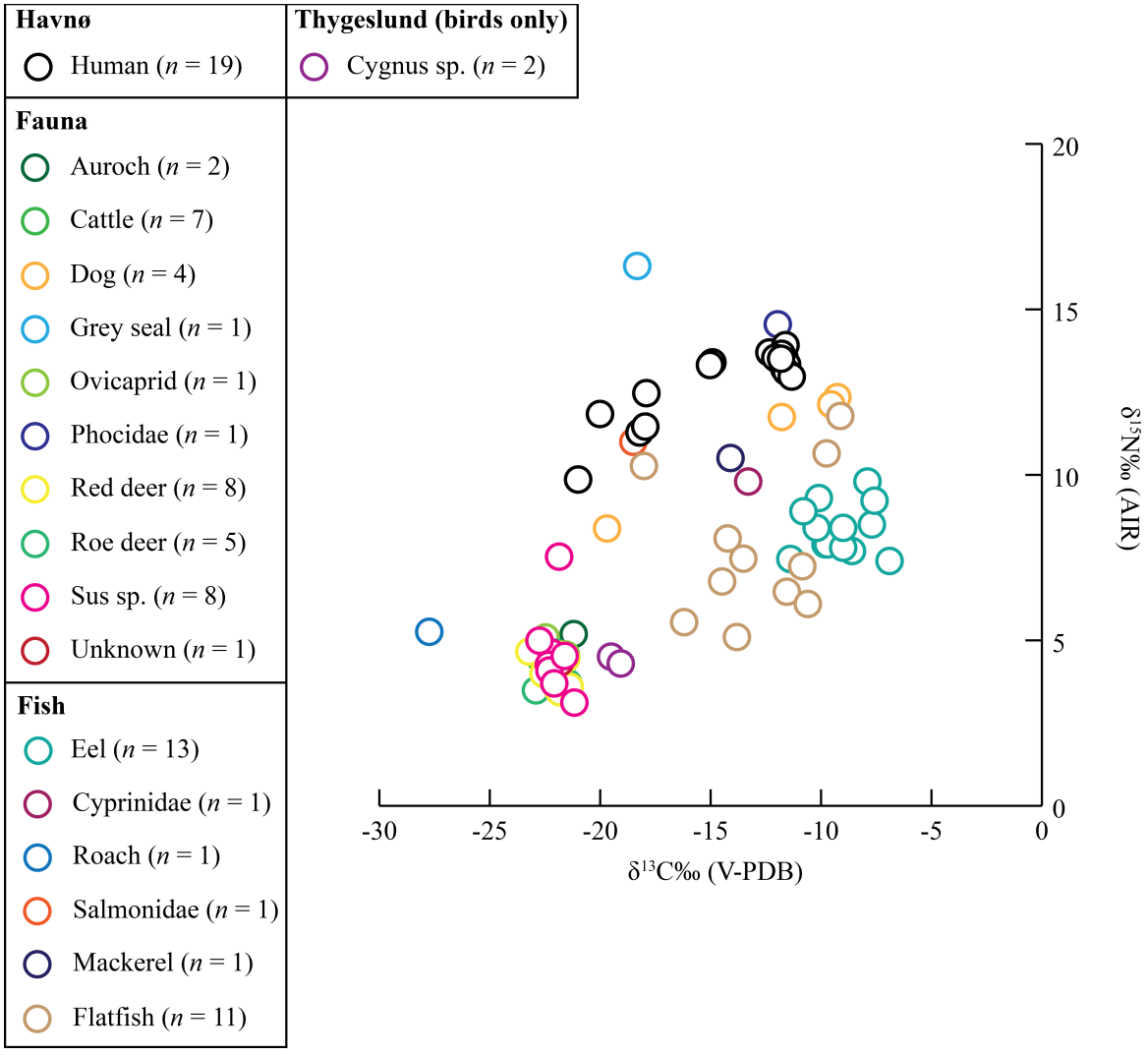


Figure 3.38: Carbon and nitrogen isotope data obtained from bird, fish, human and mammal bone collagen from the Havnø and Thygeslund kitchen middens (Gron 2013a; Robson et al. 2012).

Based on provenance alone all three domesticated dog specimens sampled from Havnø were dated to the EBK. Despite the inherent issues associated with the MRE in Danish

fjord systems, (Heier-Nielsen *et al*. 1995), in this study one has been dated to the TRB. Interestingly this specimen had a $\delta^{13}C$ value of -9.3‰ and a $\delta^{15}N$ value of +12.4‰ indicative of the long-term consumption of marine derived protein. Unfortunately the one specimen with the most depleted $\delta^{13}C$ value remains undifferentiated in terms of relative age. Conceivably this individual could date to the TRB or later, and possessed similar $\delta^{13}C$ and $\delta^{15}N$ values to that of the outlying swine (Gron 2013a). The stable isotope data are comparable with the human remains as well as previously published data (n = 41, Craig *et al*. 2006; Fischer *et al*. 2007; Gron 2013a; Richter and Noe-Nygaard 2003).

Whilst grey seals are not migratory, there are three modern populations in the general region: (1) in the western North Atlantic, (2) in the eastern North Atlantic and, (3) in the Baltic Sea that exist independently of one another (Glykou 2014). In comparison with grey seal bone collagen isotope data from Denmark (Craig *et al*. 2006; Gron 2013a), two groups have been identified, with one showing a largely extreme marine protein derived diet, and the second showing more depleted $\delta^{13}C$ values. While this difference most probably represents the life history and habitat use of the grey seal, and the Baltic Sea's salinity gradient from the east to the west (Kaiser *et al*. 2005), the grey seal specimen analysed from Havnø was probably a Baltic Sea resident (Gron 2013a).

Despite the fact that the Phocidae specimen could not be further identified to the lower genus and species taxonomic levels, grey, harp and ringed seals have been identified at coeval sites in the region (Glykou 2014). The Phocidae specimen possessed more elevated $\delta^{13}C$ and $\delta^{15}N$ values indicative of the consumption of marine protein higher up in the trophic level hierarchy, and most probably represented an individual that fed and lived in the eastern North Atlantic, that is, the North Sea (Craig *et al*. 2006).

3.8.2. Food Reconstruction Using Isotopic Transferred Signals

In this study, the Bayesian mixing model FRUITS was applied to the stable isotope data of the five human individuals from Havnø, and the one inhumation burial at Holmegård. Estimations on concentration, and the stable isotope data of the relevant food groups (Gron 2013a; Robson *et al*. 2012) have permitted an accurate quantification of the overall

consumers' diet.

While the stable isotope data demonstrated that a dietary shift had taken place across the Mesolithic-Neolithic transition at Havnø, the assumed dietary scenario predicted that when all potential food groups are taken into consideration, marine fish continued to be consumed. With the exclusion of adult (1) the dietary scenario predicted that all individuals had consumed marine fish. Although the stable isotope data on adult (2) from Havnø and the adult from Holmegård demonstrated a diet consistent with the consumption of marine derived protein, the dietary scenario predicted that C_3 wild plants had been consumed. Although FRUITS is based on numerous assumptions, this prediction is accurate especially when one considers other lines of evidence, for instance adhering food crusts on EBK ceramic vessels (Chapter 5) and floral assemblages (Andersen 2009).

3.8.3. Sulphur stable isotope analyses

3.8.3.1. Human remains

Although the carbon and nitrogen stable isotope dataset for the Danish EBK and TRB is remarkably impressive, the sulphur stable isotope data is reliant on the one previous study (Craig *et al*. 2006). With this caveat in mind, sulphur stable isotope analysis was attempted for 10 samples from Havnø, albeit with varying degrees of success. These data should be treated with a degree of caution until additional analysis is undertaken. However, some noteworthy observations were made.

In the study by Craig *et al*. (2006) faunal materials were sampled from the stratified Bjørnsholm and Norsminde kitchen middens. The following, however, will only concern the Bjørnsholm data in light of the recent re-analysis of the Norsminde faunal assemblage (Gron personal communication 2015), which has demonstrated that some of the specimens sampled were erroneous identifications.

Interestingly, the $\delta^{34}S$ value of adult two from Havnø was not consistent with the range established for marine mammals (Fry 1988) despite the $\delta^{13}C$ and $\delta^{15}N$ values that indicated

the long-term consumption of marine derived protein. Moreover, adult two had a $\delta^{34}S$ value that was within the ranges established for freshwater and estuarine birds, fish and terrestrial mammals (Nehlich and Richards 2009; Nehlich *et al*. 2013). For comparison, adult two had broadly similar $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ values with a grey seal as well as six domesticated dogs from Bjørnsholm. Similarly, juvenile one plotted with a domesticated dog from Bjørnsholm and had broadly similar stable isotope data (Craig *et al*. 2006). While these data could be a reflection of the varying quantities of sulphate $\delta^{34}S$ values in the Baltic (Craig *et al*. 2006), it does not explain why adult two with the most depleted $\delta^{34}S$ value had the most elevated $\delta^{13}C$ value. Figure 3.36 plots the $\delta^{13}C$ values against the $\delta^{34}S$ values for the four samples that yielded reliable data. It can be seen that these data exhibited a negative correlation, suggesting that, at least in this study, the Havnø specimens with depleted $\delta^{13}C$ values had elevated $\delta^{34}S$ values. Indeed two hypotheses were posited in the previous study (Craig *et al*. 2006): (1) depleted sulphur entered the marine food chain, and (2) post depositional contamination of terrestrial sulphur. However, the latter is to be considered unlikely given the established ranges for sulphur percentages, C:S and N:S ratios (Nehlich and Richards 2009). On the other hand it seems more than likely that the elevated $\delta^{34}S$ values are derived from the consumption of resources whose habitat had been influenced by freshwater inputs, that is, an estuarine or coastal environment (Nehlich and Richards 2009; Nehlich *et al*. 2013). The $\delta^{34}S$ value for juvenile one was harmonious with the location of the kitchen midden that would have been located in the mouth of the Mariager Fjord at the time of material deposition. At the very least the individual probably incorporated sulphur derived from the consumption of terrestrial resources.

3.8.3.2. Mammal remains

The two roe deer specimens analysed in the study had identical $\delta^{34}S$ values of +15.8‰. This was surprising since the samples represented two right metacarpals that were unequivocally derived from different individuals. The $\delta^{34}S$ values were marginally above the estuarine-marine threshold (Fry 1988), as such, the contribution of sea spray cannot be excluded (Craig *et al*. 2006; Zazzo *et al*. 2011). Out of the sample set the roe deer had the most depleted $\delta^{13}C$ values, and the most elevated $\delta^{34}S$ values (Figure 3.39). On the whole, these data indicated that the roe deer from Havnø resided in an estuarine or coastal

environment *ante mortem*, and not further into the hinterland. It is possible that they are derived from the coastal plains along the shoreline of the Mariager Fjord where they were hunted, killed and taken to the island.

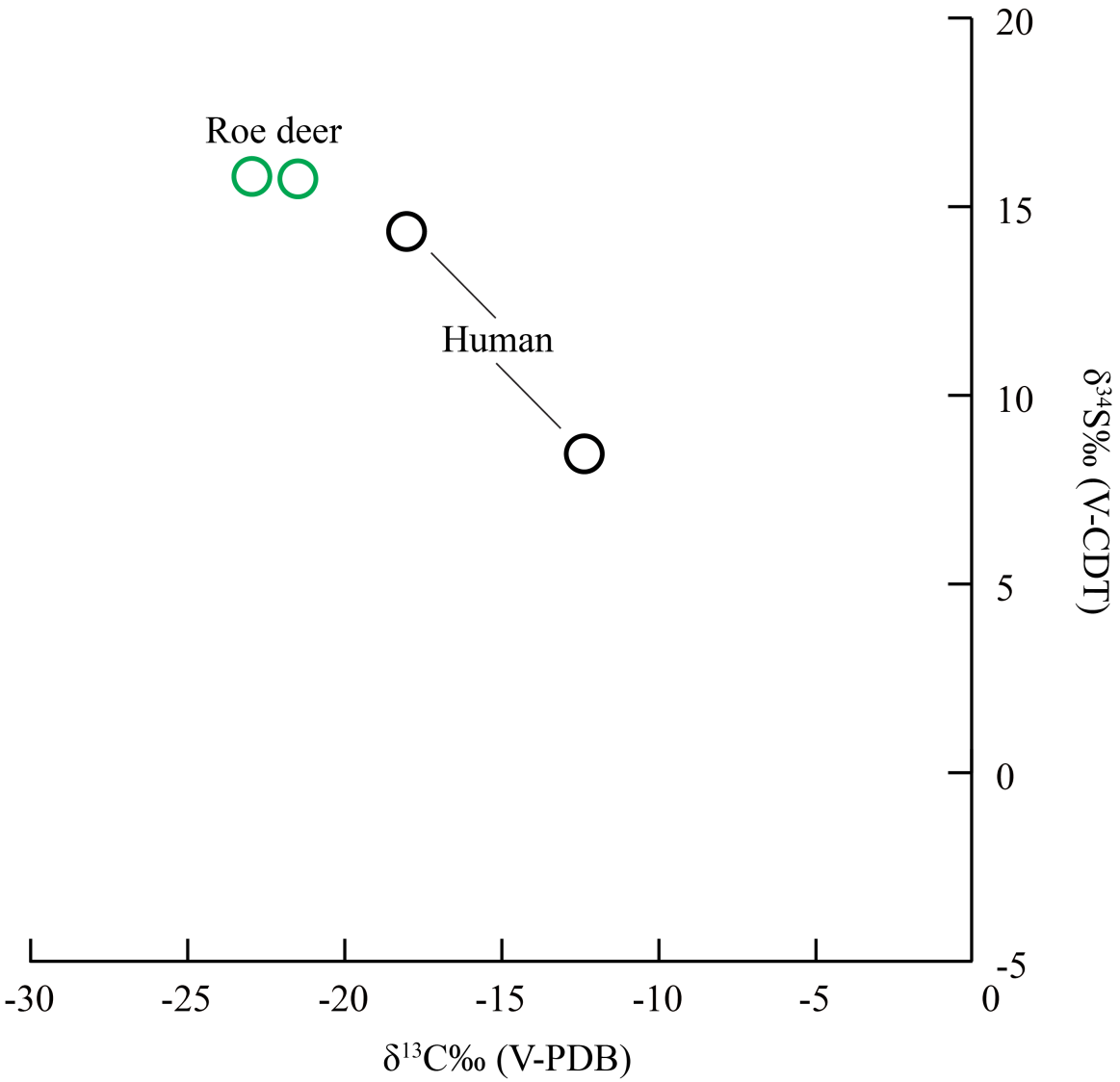


Figure 3.39: Carbon and sulphur isotope data obtained from human and mammal bone collagen from the Havnø kitchen midden.

3.8.4. AMS radiocarbon dating

In Denmark the onset of the Neolithic is marked by the introduction of domesticated fauna and flora, which is assumed to have been regularly practiced from ca. 3950 cal BC (Fischer *et al*. 2007; Noe-Nygaard *et al*. 2005). On the whole it has been argued that this

introduction was marked by a change in the consumers' diet (Clutton-Brock and Noe-Nygaard 1990; Fischer *et al*. 2007; Noe-Nygaard 1988). However, these data are not always comparable especially when the variable MREs in Danish fjord systems (Heier-Nielsen *et al*. 1995) are taken into consideration. It was for these reasons why five human remains from the kitchen midden were AMS radiocarbon dated. Overall, these data confirmed the presence of at least four different individuals in the assemblage, and clarified the observed dietary change as evidenced by the stable isotope analysis. In addition, the preponderance of Neolithic individuals in the Havnø assemblage is significant. Equally, the AMS radiocarbon dates are important as they alone double the current dataset derived from human remains recovered from kitchen middens.

Given the long chronology of site use, the dated individuals are important as they confirmed intermittent deposition over the course of accumulation. When these data are plotted spatially (Figure 3.40) it can be seen that the human remains recovered from the outlying squares to the rear of the midden proper are probably later intrusions. The nature of the shell deposits in this area of the site as well as the variable AMS radiocarbon dates attests to this. To the south, that is the midden proper where the midden sequence was thickest, there is no doubt that adult (2) was deposited and intermixed with other cultural debris over the course of material accumulation. Interestingly, juvenile (1) appeared to have been separated at some juncture throughout prehistory. Establishing the precise mechanism for this re-location is not possible at this stage given the complex depositional histories of kitchen middens as well as the numerous taphonomic agents affecting bone material over the course of deposition (Marean *et al*. 1984).

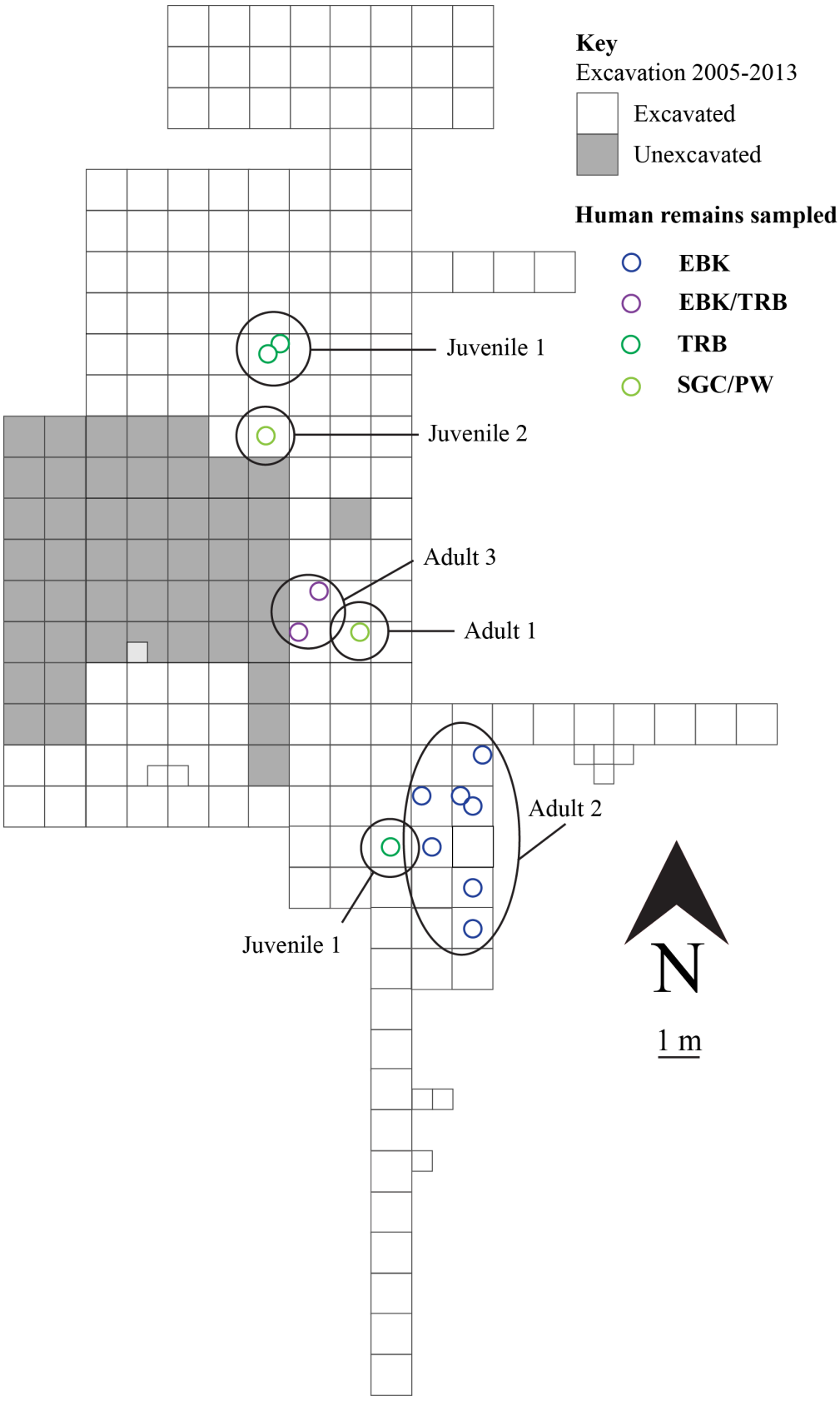


Figure 3.40: The full extent of the Havnø excavations and the dated human remains in this study.

For comparison, the AMS radiocarbon dates measured on humans recovered from contemporaneous kitchen middens were collated. These data are listed in Table 3.9 and were re-calibrated at ± 1 sigma using the University of Oxford Radiocarbon Accelerator Unit calibration programme OxCal 4.2 (Bronk Ramsey 2009) by applying a marine reservoir correction based on local marine mollusc data that was derived from a digital resource, the ^{14}CHRONO Centre, Queens University Belfast (www.calib.qub.ac.uk). Interestingly, all 12 human individuals recovered from the nine kitchen middens had broadly similar AMS radiocarbon dates when compared to the four human individuals from Havnø. Overall, these data imply that the deposition of human remains at Danish kitchen middens was carried out from the EBK to the SGC-PWC cultures.

Site	**Lab code**	**C14 age BP**	**Calibrated age at ± 1 sigma**
Bjørnsholm	K-5819/T1 (M70906)	4600 ± 75	3510-2930
Bjørnsholm	K-5820/T2 (M70907)	4310 ± 65	3010-2500
Bjørnsholm	AAR-4028/BCH198: 20a+b	4490 ± 55	3340-2880
Dyrholm	POZ-17034/ACQ59: 16+26	6680 ± 50	5070-4670
Ertebølle	K-4933/AAR-8555/E. 2842	5790 ± 30	4470-4230
Holmegård	OxA-118/OxA-533/K-3559	6145 ± 110	4550-3980
Kassemose	K-4592/M71190	3980 ± 60	2580-2140
Norsminde	K-5199/AAR-8556	5795 ± 65	4170-3690
Rødhals	AAR-8552	5360 ± 50	3870-3700
Vængesø I	AAR-4499/BCH198: 45a+b	5805 ± 45	4220-3750
Vængesø II	K-3920/BCH198: 45a+b	5500 ± 70	3950-3500
Vængesø II	K-3921/BCH195: 13+14	5540 ± 65	3960-3530

Table 3.9: Re-calibrated AMS radiocarbon dates from human remains recovered from Danish kitchen middens (Andersen et al. 1986; Fischer et al. 2007; Gillespie et al. 1984; Rasmussen and Rahbek 1993; Tauber 1988, 1990).

Figure 3.41 plots these data against the δ^{13}C values. Based on these data alone it can be seen that there was a dietary shift across the Mesolithic-Neolithic transition at the Havnø kitchen midden. However, the shift was not as dramatic or sudden as demonstrated by some scholars (Richards *et al*. 2003b; Tauber 1981) for five of the early Neolithic individuals recovered from contemporaneous kitchen middens. On the whole it would appear that these individuals continued consuming marine derived protein for several centuries at the beginning of the TRB. Despite the small sample size (n = 16) the data imply a more gradual

replacement of marine resources when domesticated fauna and flora became more readily available. These data are important since they emphasise the importance for examining sites in detail, and for not assuming a dietary change across the Mesolithic-Neolithic transition as a whole.

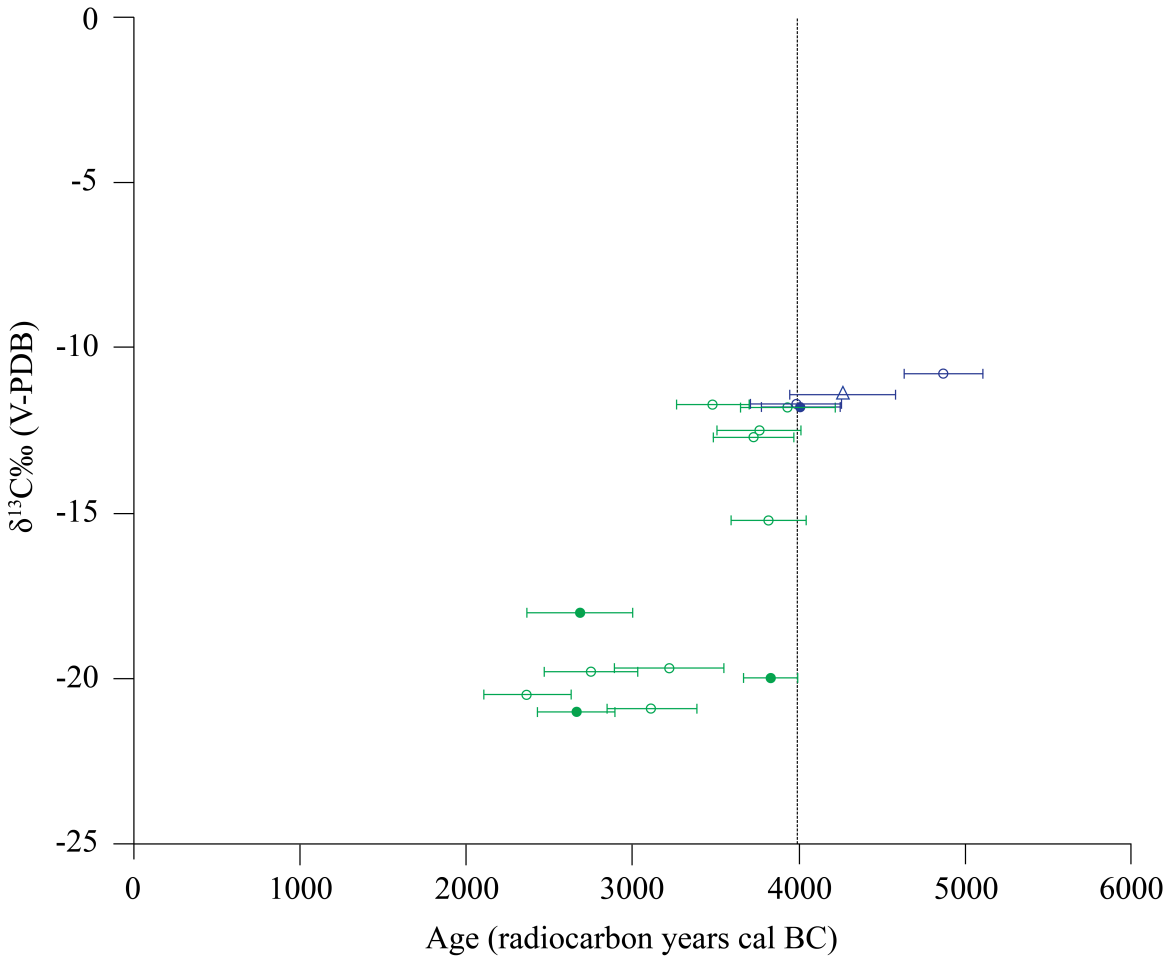


Figure 3.41: Re-calibrated AMS radiocarbon dates against carbon isotope data obtained from human bone collagen from the Havnø (filled ellipses) and Holmegård (triangle) kitchen middens compared with previously published data (open ellipses) derived from sampled kitchen middens.

3.9. Conclusions

At Havnø there was clear dietary change between the five individuals deposited at the kitchen midden. Adult (2) had principally consumed marine derived protein, whereas adults (1) and (3) as well as juveniles (1) and (2) had probably consumed a combination of aquatic

and terrestrial derived protein as demonstrated by their variable $\delta^{13}C$ values and slightly elevated $\delta^{15}N$ values. However, it is worth reiterating that the carbon and nitrogen stable isotope data are representative of the long-term diet of the consumer, and as such have many limitations. The Bayesian mixing model FRUITS demonstrated that there may have been some contribution from aquatic derived protein for adult (1) as well as juveniles (1) and (2) but the probabilities are low. When other lines of evidence are taken into consideration, aquatic birds and mammals (Gron 2013a), fish (Chapters 5 and 6) as well as oysters (Chapter 4) continued to be exploited, processed and consumed during the Neolithic.

In order to reconstruct the human diet as well as the environment and ecology of the Mariager Fjord during the use of the kitchen midden, a comprehensive stable isotope study on the fish and mammal remains was carried out. Some of these data have previously been reported (Gron 2013a; Robson *et al*. 2012). Overall these data demonstrated that the Neolithic terrestrial herbivores, and domestic cattle had been feeding in similar environments. In addition, these environments were probably more open than those reported elsewhere for Mesolithic forest-dwelling species (Gron 2013a). With the exception of one specimen, the swine do not appear to be omnivorous. It is likely that the outlier had probably been introduced from elsewhere either as body parts or when alive. Moving to the fish, the eel mackerel and flatfish are likely to have resided in the sea and/or brackish carbon pools prior to capture (Robson *et al*. 2012). However, given the disparity between the eels and flatfish, the inhabitants at the kitchen midden probably ventured into the Kattegat proper for marine derived protein, and did not solely rely on the aquatic resources of the Mariager Fjord. Interestingly, one roach specimen dating to the TRB had unequivocally derived from a freshwater carbon pool. Given that there would have been an absence of freshwater sources on the island, the specimen must have been taken there, perhaps dried or smoked. Either this represented movement between the coast and hinterland or the result of exchange between coastal and interior groups.

Additional work is required in order to characterise the variation in sulphur stable isotope values of faunal and human bone collagen. However, the analysis undertaken in this study

demonstrated that one individual had probably been consuming terrestrial resources, notably roe deer given their broadly similar sulphur stable isotope values. In addition, the roe deer had probably been residing on a coastal plain since their sulphur stable isotope values were consistent with the established range for marine mammals. It is likely that marine derived sulphate had been incorporated into their body tissues through the consumption of flora that had been affected by sea spray or coastal precipitation. In comparison, a second individual had a more depleted sulphur stable isotope value that was consistent with the consumption of estuarine and freshwater foodstuffs.

The AMS radiocarbon dates indicated a considerable duration of use at the kitchen midden in the region of 2660 radiocarbon years. Moreover, this range represented time averaged layers and short periods of intermittent use. In addition, it was assumed that the stable isotope data probably represented two groups, Mesolithic and Neolithic individuals, and this conjecture were confirmed by the AMS radiocarbon dating. Overall these data demonstrated that there were at least three different periods of human deposition at the kitchen midden.

4. European oyster (*Ostrea edulis*, Linnaeus, 1758) seasonality and intensification of exploitation

4.1. Introduction

This chapter commences with a history of shellfish seasonality research. This will be followed by an outline of the methods and sampling procedures that have been developed for the incremental growth line analysis of shellfish in order to examine both the season of gathering and the intensity of exploitation. In order to build on previous research, the incremental growth line analysis of oysters from the Havnø kitchen midden will then be presented. This is particularly pertinent to the debates surrounding the degree of subsistence change across the Mesolithic-Neolithic transition since previous research has often neglected the importance of mollusc exploitation. In addition, the analysis of oysters can provide an indication as to when the site was occupied and an impression of site use.

There were two main objectives:

- To determine whether there was a strong spring season of death (as identified in the pilot study by Milner 2002a), and whether this was consistent across the EBK and into the TRB.
- To examine the changing size of oysters through the kitchen midden in order to ascertain whether this was a product of intensive exploitation.

For inter-site comparison, five additional archaeological sites dating from the middle Mesolithic Kongemose to the Single Grave cultures were sampled: the Brovst, Ertebølle (*locus classicus*), Holmegård, and Kalvø kitchen middens, and the submerged settlement at Tybrind Vig. In addition, thin sections that had been previously constructed from five other sites by Nicky Milner and Eva Laurie were analysed: Bjørnsholm, Dyngby III, Eskilsø, Vængesø III and Visborg. Furthermore, published results of oyster seasonality and age/size analyses for seven kitchen middens at Dyngby I, Eskelund, Havnø, Krabbesholm II, Lystrup Enge, Norsminde and Visborg have been examined (Bailey and Milner 2008;

Laurie 2008; Milner 2001a, 2002a, 2005, 2013; Milner and Laurie 2006, 2009). Thus, the Havnø data can be interpreted within the context of 16 Danish archaeological sites.

4.2. Incremental growth line research

4.2.1. History of research

Since the close of the 19th century, annuli (annual growth lines) have been recognized from the cross sections of shell on numerous mollusc species (Claassen 1998). Despite its first application in 1914 (Isely 1914), growth line analysis was not applied to archaeological material until the 1960s and 1970s (Chace 1969; Perlman 1973; Shackleton 1973; Weide 1969). During the 1960s a number of articles appeared in the malacological literature that demonstrated that material is only deposited whenever the mantle is extended, thus deposition is affected by a number of host variables, which are periodic in expression, for example tidal regimes (Claassen 1998).

When bivalves grow they deposit increments of shell material, including calcium carbonate (CaCO3) on the margins of their valves and/or hinge. Shellfish grow incrementally in a similar manner to trees however growth patterns are not only species-specific but are also modified by latitude as well as local shore conditions (Deith 1983a). Thus, growth varies throughout the year, resulting in a patterning of increments in the form of annuli or other bands/breaks in the shell microstructure that are often different in colour and structure (Milner 2001b).

The research undertaken by geologists House and Farrow (1968) on the cockle is considered one of the most definitive works for the development of incremental growth line analysis for archaeologists. Their work demonstrated that the lines visible on the surface of the shell (macro-lines) were the result of a recession during the winter, whereas the micro-lines, which were observed from the photomicrographed cross sections of the shells, represented daily bands.

Coutts (1970) was largely influenced by the work of House and Farrow (1968), and carried

out analysis on the New Zealand cockle (*Chione stutchburyi*). This was probably the first application of incremental growth line analysis to archaeological material. In total, 12 modern shells collected over a 12-month period were sampled (Coutts 1970). Since there was a mean of 358 micro-lines per annum, these data demonstrated to the author that each line formed daily. Provided that the approximate date for the formation of macro-lines is known, the month of collection for both the modern and archaeological samples was estimated with a margin of error of ± three months. The interpretation was based on examination of the thickness of the daily bands from the last macro-line to the shell margin (Coutts 1970).

In the early 1970s the understanding that the formation of micro-lines in cockles was a daily phenomenon was utilized by Farrow (1971, 1972). However, it was later noted by Coutts (1974, 1975), that cockle growth patterns did not appear to follow either logical nor easily defined and interpretable sequences. Therefore, it was concluded that additional work was required on modern specimens prior to seasonal dating. This problem however, was subsequently resolved in 1979 when the internal micro-growth bands that were deposited on the cockle were quantified. The analysis demonstrated that the bands coincided with the number of tidal immersions, i.e. two lines that formed daily (Richardson *et al*. 1979).

The aforementioned combined with an independent modern control sample was later used by Deith (1983a) in order to interpret the season of gathering for the cockle from the Mesolithic site at Morton, Fife. Overall, the analysis demonstrated that the macro-lines were formed during a period of growth recession during the cooler months of the year, notably winter, and the tidal micro-lines were shown to form between the months of late April and late September. For these five months the seasonal resolution was thought to be credibly accurate, but for the remaining months of the year a blanket category of ‘winter collection’ was used (Deith 1983a).

Since the revolutionary research by Deith (1983a, 1983b) numerous incremental growth line analyses have been conducted. For instance, an additional study on the cockle has been

undertaken (Laurie 2007, 2008) in order to determine to what extent the consumption and exploitation of this species changed across the Mesolithic-Neolithic transition in Denmark. Incremental growth line analysis of the European oyster has also been pioneered and applied to specimens from numerous archaeological sites throughout Europe (Gutiérrez Zugasti and Laurie 2006; Milner 2002a, 2009; Zapata *et al*. 2007).

In general, the field of sclerochronology has developed considerably since the 1980s, and now incorporates numerous scientific disciplines including archaeology, biology, climatology, ecology, environmental sciences, geochemistry and paleontology-to name but a few (Thomas 2015). Recently, two review papers are available. The first (Andrus 2011) detailed the applications, methods, problems and potential within the discipline of archaeology, whereas the second (Schöne and Gillikin 2013) focussed on the application of trace elements and stable isotope analysis as a proxy for environmental reconstruction.

In terms of approach, ascertaining the season of death of archaeological molluscs has largely been undertaken from an economic perspective in order to determine subsistence scheduling, site function, and settlement patterns (Bailey 1978; Jarman *et al*. 1982). However, the analysis of molluscs offers the potential to assess when they had been harvested allowing site function, settlement patterns and subsistence scheduling to be reconstructed (Milner 2005).

4.2.2. Incremental growth of the European oyster

The European oyster produces annual lines that are visible on their shell hinges. They are formed by a break in growth during the cooler periods of the year due to a drop in water temperature and food availability. It is during the winter when the oyster enters a state of hibernation when respiratory and heartbeat may cease, and ciliary action maybe reduced (Yonge 1960). When water temperatures increase during the spring and food becomes more available, the metabolism of the organism increases and the mantle will start to deposit calcium carbonate on the margin of the shell (Milner 2002a). Thus, the amount of growth between the last band and the growing edge provides an indication as to the season of exploitation. Whilst incremental growth lines can be viewed on the exterior of the shell, in

order to obtain a more detailed perspective on seasonal growth it is necessary to section the oyster hinge and inspect the structure microscopically (Milner and Laurie 2009).

While a large modern control sample is desirable, many studies do not include them, thus assumptions regarding when the lines formed and why they are made remain unanswered. Additional problems arise during interpretation, including how the seasonality data are analysed and subsequently interpreted. The mean growth data are often used in order to assign the period of harvest to individual shells.

However, averaging and standardisation of growth line data has shown to be normative and liable to produce erroneous results (Claassen 1998). Basic assumptions regarding shell growth are often used and have shown to influence the prediction of the season of harvest. Many growth controls are necessary in order to show that the shells do not respond to growth stimuli identically, and that the timing in response to those stimuli is not annually predicable.

The requirements for correlating demographic characteristics include controlled growth from several years, numerous size classes, mean and median shell size, and a large sample set. For example two years or more of controlled collections are preferable (Claassen 1998; Laurie 2008; Milner 1999, 2002a). Obviously the degree of variability, determined from such analyses, including STDV and range, will affect archaeological interpretations considerably, especially if the site is small and considered to have been visited primarily for the purposes of shellfish exploitation.

The research presented here used the analysis formulated by Milner (2001b) who studied the incremental growth pattern of the European oyster through the examination of modern control samples that were collected at monthly intervals over a period of 16 months. They were taken from three different locations along the British coastline as well as oysters that had been farmed at Whitstable. All were of known age. In total 484 shells were analysed by examining thin sections of the hinge of the shell (Milner 2001b). The right (upper) valves were, in general, selected for thin sectioning since the left (lower) valves often contain

more cavities that break up the structure and inhibit interpretation. Therefore, thin sections were made from the hinges and seasonality as well as age/size data for each oyster was ascertained through microscopic examination (Milner 2002a). In the present study oysters were analysed using the same method.

The data from the modern control sample showed that annual growth lines appeared to form during the spring, mainly March and April, when warmer water temperatures facilitate the increased growth of plankton (Milner 2002a). Thus, oysters that possessed a line on the edge had died during the spring (March or April). Shells that had died in May or June were also identified because the annual line is very close to the growing edge, although some growth should also be taken into consideration. As the year progressed and the growth rate decreased during the autumn and winter, it became harder to recognise the time of death. However, there are indicators at the top of the shell. Usually there is a distinctive topography and with every annual line this ‘dips’ down when a line is about to form (Figure 4.1) (Milner 2001b, 2002a).

When analysing the thin section it is important to consider three other types of disturbance lines: the conchiolin line, the midlines and 'others' (Milner 2002a). Conchiolin is a fibrous, insoluble tough protein that forms the organic matrix of the shell within which the calcium carbonate deposited. The mantle forms this protein when the nacreous layer of the shell is damaged (Milner 2001b). Although yellowy greenish in colour, and thus different when compared to annual growth lines, scrutinization under a microscope by the analyst is required in order to distinguish between these disturbance lines and the annual lines. Midlines create the most problems regarding interpretations since they can be mistaken for annual growth lines. These are assumed to be the result of spawning, and occur approximately halfway through the band of growth. After the initial spawning, the oyster changes sex. This metamorphosis from female to male is rapid, and may be completed within several days as opposed to the change from male to female that may take a period of weeks (Milner 2001b). Midlines may also result from growth disturbance caused by brief but violent storms, prolonged periods of poor weather or predation (Milner 2001b).

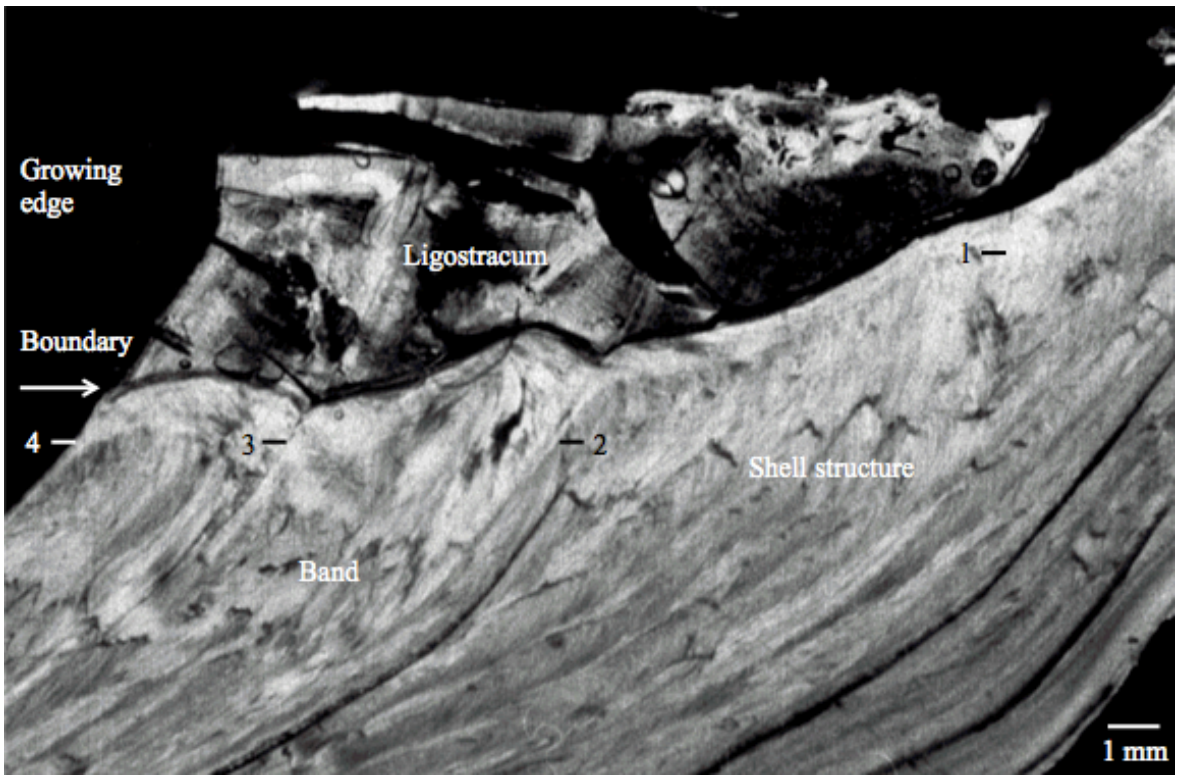


Figure 4.1: Thin section of oyster (C.3.E.18.R) from the River Crouch, Chelmsford that had died in May: there are four annual lines with one very close to the edge. The boundary between the shell structure and the ligostracum shows a patterned topography: towards the end of the winter the top of this 'dips' downwards until it forms a new line (photograph courtesy of Nicky Milner and modified by the author).

In the study conducted by Milner (2001b, 2002a) the thin sections were initially analysed by the researcher. In order to test the results, they were then subjected to a blind test that was undertaken by a second individual. The results were compared and any discrepancies were discussed. Since it was not possible to identify the month of death precisely, seasonal interpretations were made. It was demonstrated that seasonal estimates had a margin of error of ± one month, consequently evaluations are accurate to within a season (Milner 2001b, Milner and Laurie 2009). Seasons in the temperate northern hemisphere are broadly defined as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).

4.2.3. Intensity of exploitation

Claassen (1998, 45), has listed a number of ways in which scholars have identified overexploitation including: (1) a decrease in the mean shell length from the bottom to the

top of a deposit, (2) the modal size of the archaeologically derived population of a species, when examined against figures for an unexploited population, will be significantly smaller, and (3) less easily procured individuals or species that increase in number from the bottom to the top of a deposit. Thus, changes in the species composition through a shell midden sequence, and changes in shell size, particularly when shells have been observed as reducing in size through time, have often been argued as the result of intensive exploitation (Milner and Laurie 2009). These observations have been made on shell middens around the world, including the Asturian middens (Bailey and Craighead 2003), the Danish kitchen middens (Andersen 1989, 1991, 2008a, Andersen and Johansen 1986; Laurie 2008; Milner 2002a, 2013; Milner and Laurie 2009), the southern Californian middens (Braje *et al*. 2009; Rick 2011), and the middens of the United Kingdom (Mannino and Thomas 2001; Mellars 1978, Russell *et al*. 1995). Many of the aforementioned had been formed by hunter-gatherer-fisher peoples, who had had a substantial contribution of resources of marine origin to their diets. In general, the issue for an intensification of exploitation has often been related to human population growth and pressure on resources (Rowley-Conwy 1984).

In general, the observation that shells in many of the shell middens reduced in size over time has been partly explained by two causes: (1) a result of the intensification of exploitation and/or, (2) a result of environmental change.

Whilst is has been considered that it would have been difficult for humans to overexploit a natural population of shellfish (Claassen 1998), this notion has been debated (Mannino and Thomas 2002; Milner 2013). For instance, if the mean size of the oyster decreased alongside the mean age, it would tend to indicate that the age structure of the natural population is being depressed through harvesting. However, if the mean size decreased but the mean age remained unaltered it is assumed to have been the result of environmental change.

It is necessary to consider the possibility that environmental change could have affected the natural populations so that they grew slower and were thus collected at smaller size classes (Claassen 1998, 47). A sample of smaller oysters with similar age profiles compared to a

sample of larger oysters may indicate that environmental change had caused the decrease in shell size through time, since the annual rate of growth is slower resulting in smaller annual growth bands and thus smaller shells (Milner 2002a).

Milner (2002a) stated that it is not possible to comment on the actual influence of environmental change and human predation pressure on the oysters from the Danish kitchen middens as whole, except to note that a change through time is probably a combination of both factors.

4.3. Previous sampling strategies

Danish kitchen middens tend to have an extremely complex stratigraphy. This is largely the result of the repeated deposition of more than one localized shell heap or horizon of a single species of mollusc alongside the cultural waste over a long period of time. For example, at the Ertebølle kitchen middens more than 20-25 individual shell horizons, interpreted as individual 'meal heaps' (Madsen *et al*. 1900, 25-28) were identified and represented a period of use from ca. 5100-4100 cal BC (Andersen and Johansen 1986). These heaps are sometimes identified in section or have been identified through the stratigraphical analysis as well as column sampling. Recent excavations at multiple kitchen middens have demonstrated that shellfish gathering was a regular, and seasonal activity (Milner 2002a), since the majority of the processing, consumption and disposal of the molluscs occurred on the midden (Andersen 2000a). In addition, investigations have demonstrated that the mixture of the shell matrices is likely to be the result of the repeated cleaning of the occupation surface of refuse into specific areas of the site (Andersen 2000a; Rowley-Conwy 2013). Whilst the waste from one occupation can be interspersed with that of subsequent occupations, through careful excavations, and the refitting of artefacts it has been possible to ascertain and delineate the former living surfaces within kitchen middens (Andersen 2000a; Forschammer *et al*. 1851; Madsen *et al*. 1900).

Due to the aforementioned complex stratigraphical issues, it is necessary to estimate as best as possible the samples that are derived from contexts dating to the EBK and/or the TRB, as well as those belonging to later periods or cultures. This can be largely determined by

the associated ceramic and lithic typologies, matrix shell size, composition, location within the kitchen midden, and, in some cases by directly AMS radiocarbon dating the shells themselves.

One method for elucidating the stratigraphy is through column sampling, which has been undertaken at Bjørnsholm, Ertebølle, Havnø, Krabbesholm II and Norsminde for the diachronic analysis of molluscan species and fish remains (Andersen 1989; Andersen and Johansen 1986; Enghoff 1986, 1991; Milner 2002a, 2013; Laurie 2008; Robson 2011).

However, it has also been beneficial to sample from multiple locations from across a site in order to ensure that as many of the different depositional events as possible are examined. If molluscs, are sampled from one discrete area alone then there is the possibility that the seasonality and age/size classes/relationships from a single collection episode will be represented, which will undoubtedly be unrepresentative for the surrounding matrices or the shell midden as a whole. Thus, a sampling strategy should take into consideration the variability throughout contexts, for instance the inclusion of shell in the distribution of features (Claassen 1998).

For the majority of seasonality studies, the sample size has largely been dictated by budgetary and time constraints as well as the availability of samples at that time (Milner 2002a; Laurie 2008). Consequently there is significant variability in sample sizes between sites. Claassen (1998) has suggested that a sample greater than 20 and less than 100 shells from any one area should be analyzed in order to examine a deposit of shells that were potentially harvested simultaneously, which would result in a reliable dataset. In doing so the analyst interprets groups or shells, and not just individuals.

Furthermore, one must also be aware of the numerous taphonomic processes active on individual shells that have been deposited by peoples. In general, taphonomic processes broadly include abrasion, chemical conversion, dissolution, encrustation, fragmentation, and perforation, whilst cultural processes include heating, trampling, and the movement of the shells (Claassen 1998). For instance, there are several physical properties that can

fracture shell valves. Whilst roots penetrate the thinner portions of valves by following their crevices that result in fracture through an increase in their diameter during growth, overburden can cause compression fractures, slumping and creep (Claassen 1998). It is for these reasons why Milner (2002a) measured the oyster hinge lengths because complete valves are not always consistently preserved within kitchen middens, whereas the hinge generally survives. In addition, Claassen (1998) recommended to abstain from shells altered by heat since their original age/size classes/relationships may have been concealed and distorted: 'oysters (*Ostrea*) with their lamellar structure exfoliate completely upon extended contact with fire' (Claassen 1998, 66).

4.4. Analysis of oysters from Havnø

4.4.1. Pilot study

A pilot study of oysters from Havnø was first undertaken in 1997: Søren H. Andersen sent a small sample of 18 shells to Nicky Milner for analysis (Milner 2002a). Owing to the sample size, it was stated that the oysters should be considered as a part of an experiment with the sole intention of providing 'an indication of some of the months in which the oysters were gathered' (Milner 2002a, 91) as opposed to assessing seasonality over time for the kitchen midden as a whole.

Unfortunately there is a lack of stratigraphical information for these samples although they appear to have been extracted from an EBK layer (Andersen 2008b). Milner (2002a) stated that the shells were larger when compared to the other sites sampled and similar to those from the Visborg kitchen midden. It was demonstrated that for both kitchen middens, the oysters were older and slightly larger for their age (Milner 2002a, 93). This is not surprising since both kitchen middens are situated < 5 km away from one another in the Mariager Fjord, which appeared to have been a rich biotope during material deposition (Andersen 2008b). In addition, the shells were deemed to have been in a fairly good condition, and the majority were thin sectioned successfully (94%). Of the selected shells, 13 (76%) were interpreted successfully and the thin sections yielded clear structures that could be examined for seasonality assessment (Table 4.1). The analysis demonstrated a clear peak of

spring collection, and a discreet spread of collection events from February through to April (Figure 4.2). Although the modal month was March (n = 9.5), the sample size is very small (n = 13). However, the samples probably represent one discrete area, potentially a single collection episode and should not be used for assessing seasonality for the kitchen midden in general.

Site	Catalogued	Selected	Discarded	Thin sectioned
Havnø	18	17	4	13

Table 4.1: Table to show the numbers of oyster shells catalogued, selected, discarded and finally the total number of completed thin sections for Havnø (after Milner 2002a).

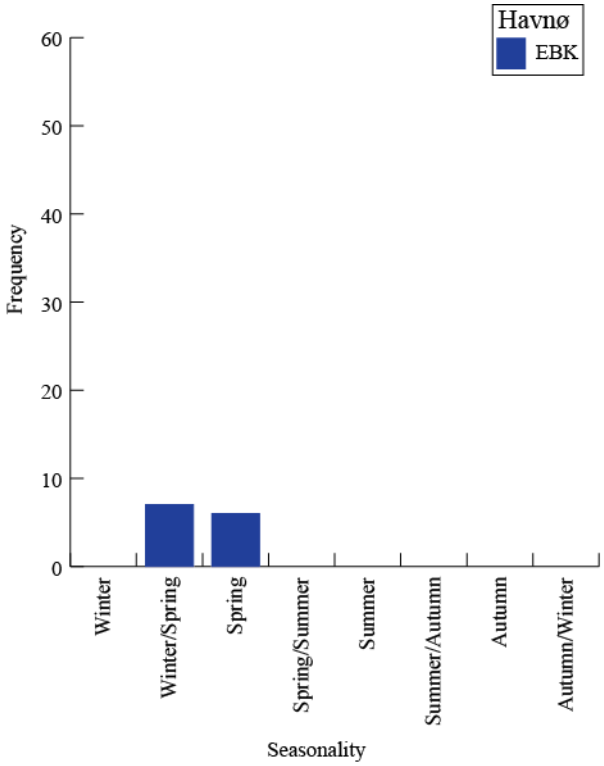


Figure 4.2: A histogram showing the seasonality of oyster gathering for the randomly selected shells. Note that the categories have been changed in this graph from the original publication for consistency with other data presented in this study (Milner 2002a).

4.4.2. Sampling

For the present study 137 oysters were selected for analysis from the Havnø kitchen midden. The aim of the sampling strategy was to obtain material from EBK and TRB contexts as well as different locations from within the kitchen midden. In total, nine oyster

samples (Table 4.2) deriving from 10 different grid squares were excavated from *in situ* contexts throughout the kitchen midden. In 2008 Hayley Saul under the direction of Søren H. Andersen excavated three samples (sample references: one, two and three) from different layers of the midden sequence. Initial sorting of these oyster samples was carried out in Denmark, and they were brought to the University of York the same year. Between 20 and 29 shells from each sample were deemed suitable for thin sectioning since some of the shells were found to be too broken or fragmentary.

Grid square	**Sample reference**	**Selected for sectioning**	**Culture**
98/101	One	24	TRB
90-91/100	Two	29	EBK
90-91/100	Three	20	EBK
112/100	UED	9	TRB
113/100	UEC	9	TRB
98-99/99	SQG	15	TRB
114/100	POL	7	TRB
96/99 SW	THR	12	TRB
97/99 SE/SW	THU	12	EBK
Total		**137**	

Table 4.2: Table to show the oyster shell samples.

The remaining six oyster samples were selected and removed from the site in 2009 by the author. These samples were selected from different layers across the site with the aim of acquiring oysters from the TRB layers in order to ensure that sufficient samples were derived from both cultures. Samples POL, UEC and UED were removed from contexts located in small scatters to the rear (north) of the midden (Figure 4.3). The remaining samples were extracted from what has been termed by Søren H. Andersen as the 'midden proper' because it is the part of the site with the thickest shell sequence, and has been dated from the EBK to the TRB.

As many oysters as possible were removed from these squares, however when the material was sorted in the laboratory a large proportion was not deemed suitable for thin sectioning. This was because the majority of the TRB shells were much smaller and also more

fragmentary than the EBK oysters. Thus, between seven and 15 shells from each sample were suitable for analysis. Of the 137 shells, 61 are derived from deposits that have been dated to the EBK, and 76 from deposits dated to the TRB.

4.5. Methods

4.5.1. Thin section manufacture

Each shell was washed with a toothbrush under cold tap water, and left to dry for 24 hours. The shell was then given a number that identified the site, the stratigraphic layer or the sample reference, and an individual shell sample number (for example the first shell from sample one read HAV1.1, the second HAV1.2 etc.), and then catalogued. The cataloguing involved taking measurements of the shell hinge length, length and weight of shell, where possible, and noting any features such as burning or mineral staining (Milner 2002a). The hinge of each shell was measured with electronic callipers in mm to one decimal place, and each shell was weighed in grams. The right (upper) valve of the oyster was generally chosen for thin sectioning.

The oysters were thin sectioned using a method developed by Milner (2001b). The oyster shells were cut from the tip of the hinge at a right angle to the growth line using a Buehler ISOMET 1000 Precision Saw (Model 11-2180), and a Buehler Diamond Wafering Blade (Series 15LC Diamond No 11-4276). Since the cutting procedure produced a right and left half, the better-sectioned half was selected and cleaned with cold water to remove residue. They were left to dry for 24 hours.

The specimens were placed face down in one and two-inch plastic moulds respectively depending upon the size of the cut hinge (Figure 4.4). The plastic moulds had also been dried and cleaned with acetone, and then coated with Buehler Release Agent No 20-8185-016. The hinges were embedded in resin (50 grams of Buehler Epo-Thin Low Viscosity Epoxy Resin No 20-8140-12B mixed with 18 grams Buehler Epo-Thin Low Viscosity Epoxy Hardener No 20-8142-016).

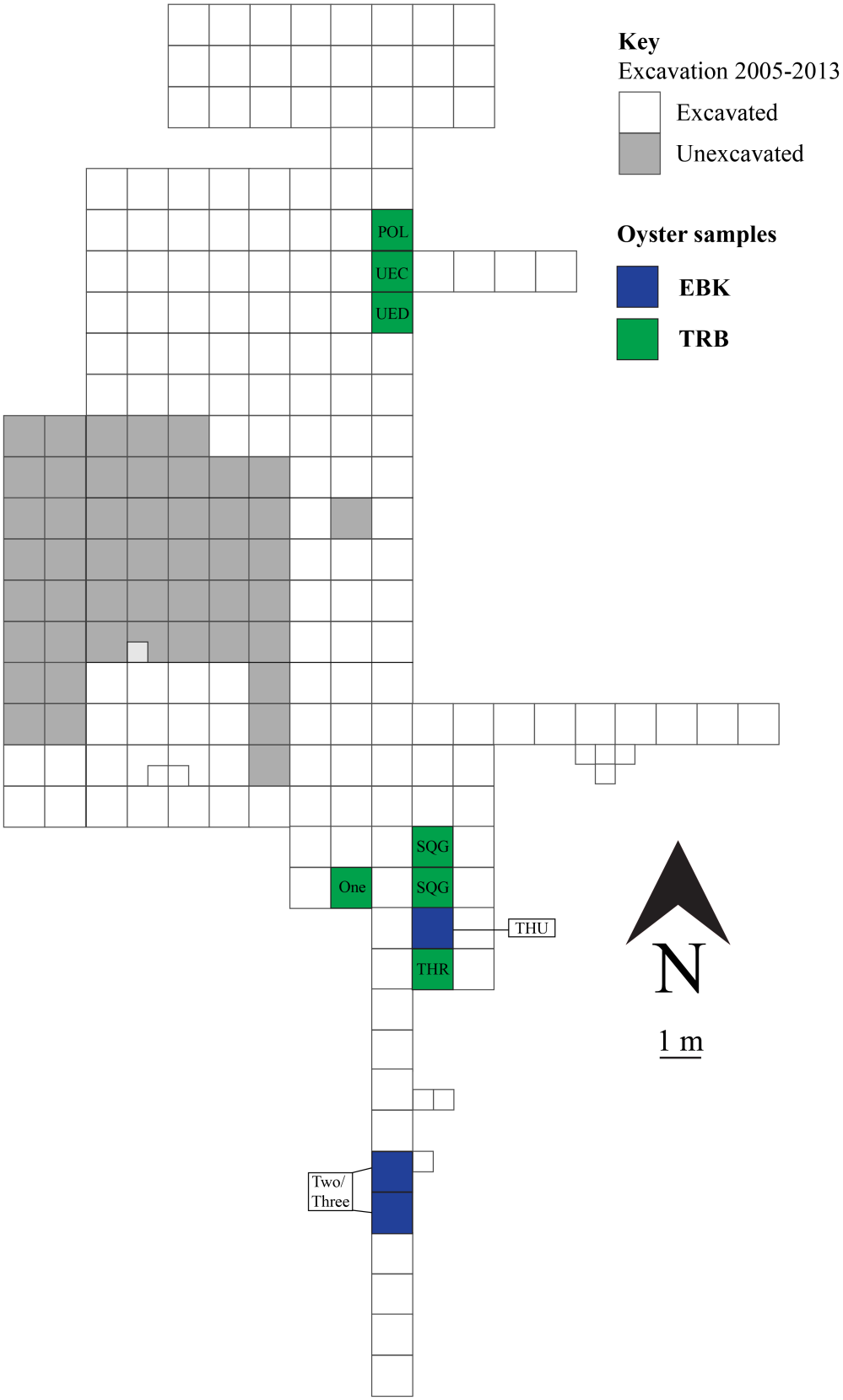


Figure 4.3: The full extent of the Havnø excavations and the oyster sample locations in this study.

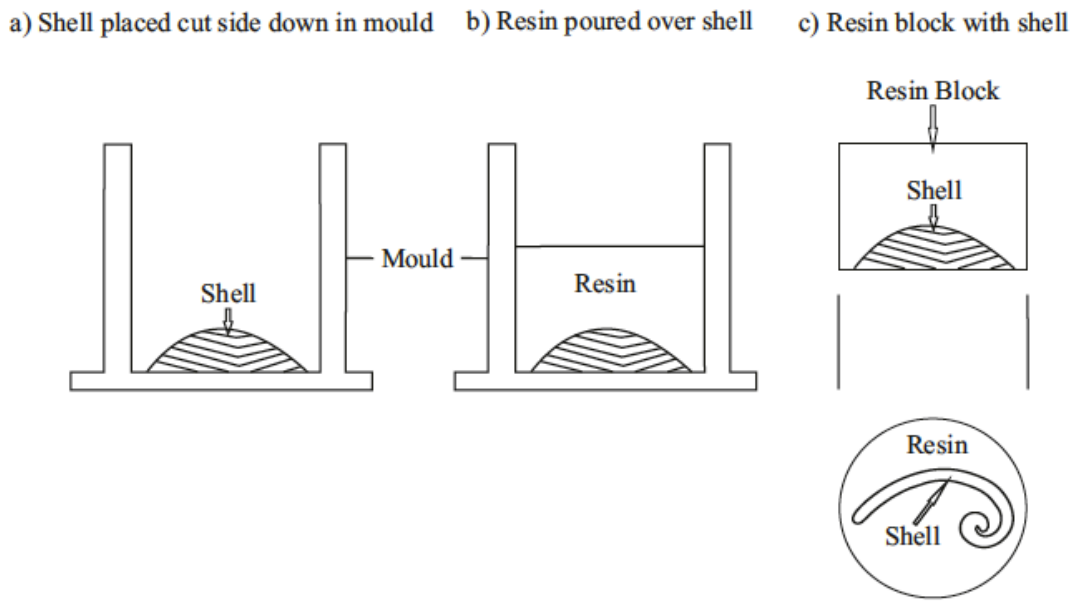


Figure 4.4: (a) Cross section of mould; (b) Cross section of resin block; (c) Cross section and birds eye view of block.

The samples were vacuum impregnated using Buehler Vacuum Impregnation Equipment (Model No 20-1384-220). The plastic moulds were placed in a vacuum chamber and vacuumed to ca. 15ºC and left to cure in an environment of constant humidity and temperature for at least 16 hours.

Once hardened, the resin blocks were removed from the moulds and labelled with a diamond pen and waterproof marker. The samples were lightly ground using successively finer metallographic grit papers (P600, P1200 and P2500 grades respectively) using a Buehler Motorpol 2000 Grinder/Polisher. The surfaces of the resin blocks were washed with tap water and left to dry. They were then polished using a Texmet polishing cloth and Buehler MetaDi 3µm water based diamond paste, rinsed with cold water and left to dry for 24 hours.

The polished facets of the resin blocks were attached to a glass slide using Loctite 322 Adhesive. They were then exposed to an ultra violet light source for ca. 5 minutes to set and left to harden for 24 hours.

Once the sample had bonded to the slide, the body of the resin block was sliced from the slide using the Buehler ISOMET 1000 Precision Saw, thus leaving a thin slice of the resin block and shell of approximately 50 to 100 μ.

In order to clearly see the microstructure of the shell, the shell and the resin were then lightly ground to produce the thin section. The slide was placed in a hand held slide holder with the sample face down and held over revolving grit papers until the final thinness was achieved. This varied from thin section to thin section and was monitored by eye as well as repeated checks under a polarizing light microscope. Lastly, the sample was polished on a Texmet polishing cloth and Buehler MetaDi 3 μm water based diamond paste. The final thin section was usually between 10 and 25 μ in thickness.

4.5.2. Examining the thin sections

The thin sections were examined under polarized light at magnifications of x10 to x40. These were compared to a collection of thin sections made on modern shells, collected from four British locations each month over a period running from December 1995 to March 1997 (Milner 2001b). The annual lines were noted for each shell and counted, any other lines such as spawning lines were noted, and the last section of growth from the last line to the outer edge was examined in order to assess the season of death using the criteria shown in Table 4.3.

Since the initial analysis (Milner 2002a), the way in which interpretations are reported has been altered. Originally, a month was assigned to each shell but this caveat had a margin or error of ± 1 month (Milner 2001b, 2002a; Milner and Laurie 2009). However, in more recent analyses, a seasonal assessment has been made. It is felt that seasons are more representative because they remove the false perception that interpretations are accurate to within a month and take into account the margin of error. However, they have also been subdivided into split seasons. The explanation of observations for each period is given in Table 4.3.

Season	Identifications
Spring	A line is present right on the edge and the edge dips down.
Spring/Summer	The shell shows a new line and a very thin band of new growth.
Summer	A band of growth between the last annual line and the shell edge.
Summer/Autumn	A larger band of growth between the last annual line and the shell edge and a spawning line may be present.
Autumn	A large band of growth but not a full year.
Autumn/Winter	A large band of growth - almost a full year.
Winter	A large band of growth which looks like a full year but no dipping on the edge.
Winter/Spring	A darkening of the growth edge begins and dipping downwards on the edge.

Table 4.3: Table to show the identification and assignments to particular season starting with line formation in the spring.

In addition, the confidence in the season varied. The highest degree of confidence was assigned to shells with a line directly on the edge indicating line formation and a spring death (March or April). This was because the line is a clear indicator. However, from the modern control study, it was clear that line formation did not occur on one day. There was variation within a population, and therefore a sample of oysters collected on one day may include oysters with lines and oysters without. This sample would be interpreted as having winter/spring and spring oysters. Thus, it is important to note that such a grouping may not indicate two seasons but possibly one collection event.

Oysters gathered during the spring/summer (ca. May, June), and summer (ca. July, August) were equally easily interpreted because their lines are close to the edge and may also include a spawning line. However, from October onwards, growth reduced significantly. Generally it is possible to identify an oyster harvested during the autumn (ca. September,

October), because there does not appear to be a full years growth. However, distinguishing between oysters harvested during the Autumn/Winter (ca. October, November), Winter (ca. December, January), and Winter/Spring (ca. February, March) was more difficult since the only indicator was the topography at the top of the shell that started to dip down when a line was due to form.

4.6. Results

4.6.1. Introduction

Of the 137 thin sections, 79 (57.7%) produced seasonality results. Figures 4.5 and 4.6 provide examples. The other 58 were either unsuccessful during the manufacturing process or were noted as unreadable during the microscopic analysis. Sometimes during the manufacturing process some of these shells broke or the hinge had been cut on a slant, which meant that a reading could not be taken accurately, and so these specimens were discarded. Furthermore, assessment under the microscope sometimes revealed that the edge appeared damaged, or the structure was affected by disturbance, and was not clear enough to provide a confident reading.

This percentage (42.3%) is fairly high: often only 20-25% will be discarded (Milner 2002a). However, it is mainly the TRB oyster shell samples that have skewed the results since they represent 63.7% of the unsuccessful and unreadable thin sections (Table 4.4). These shells were excavated from the higher deposits of the midden sequence as well as an area to the north (rear) of the midden proper, and were more visibly weathered than those shells further down in the midden sequence dating to the EBK. These oysters were also smaller and younger which meant that there are fewer complete annual bands for comparison. This also made assessment harder.

The majority of the oysters (n = 114) were measured in order to assess whether there was a change in their size. Although only 79 could be assessed for seasonality, 98 could be aged because even if they had had a damaged edge their growth lines could be counted.

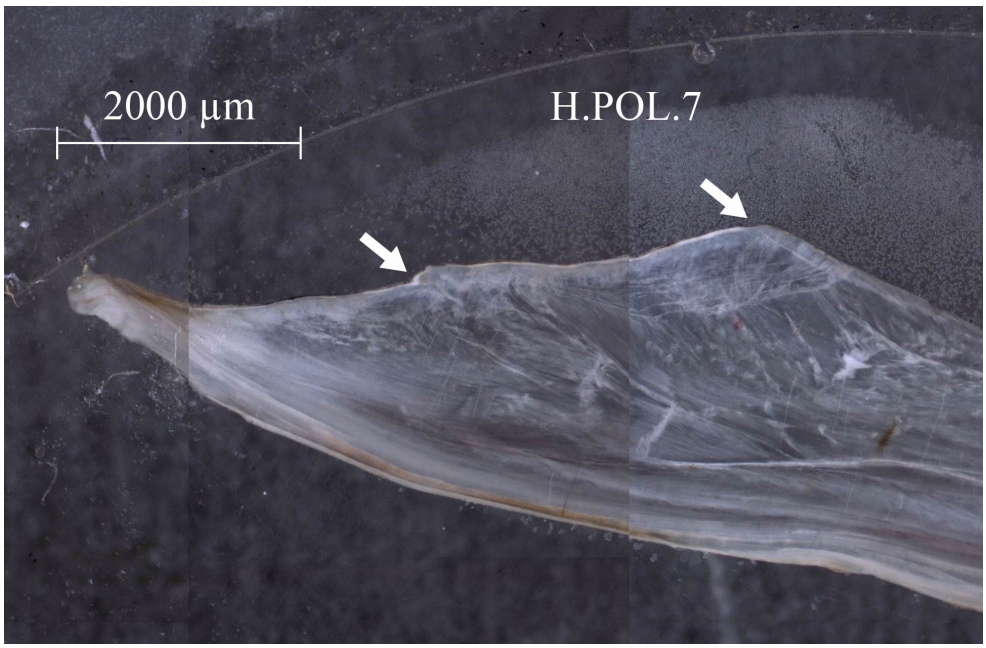


Figure 4.5: Thin section of H.POL.7 demonstrating the clear annual banding and two lines. The edge shows a new line, and a short band of new growth: this has been categorised as a spring/summer oyster.

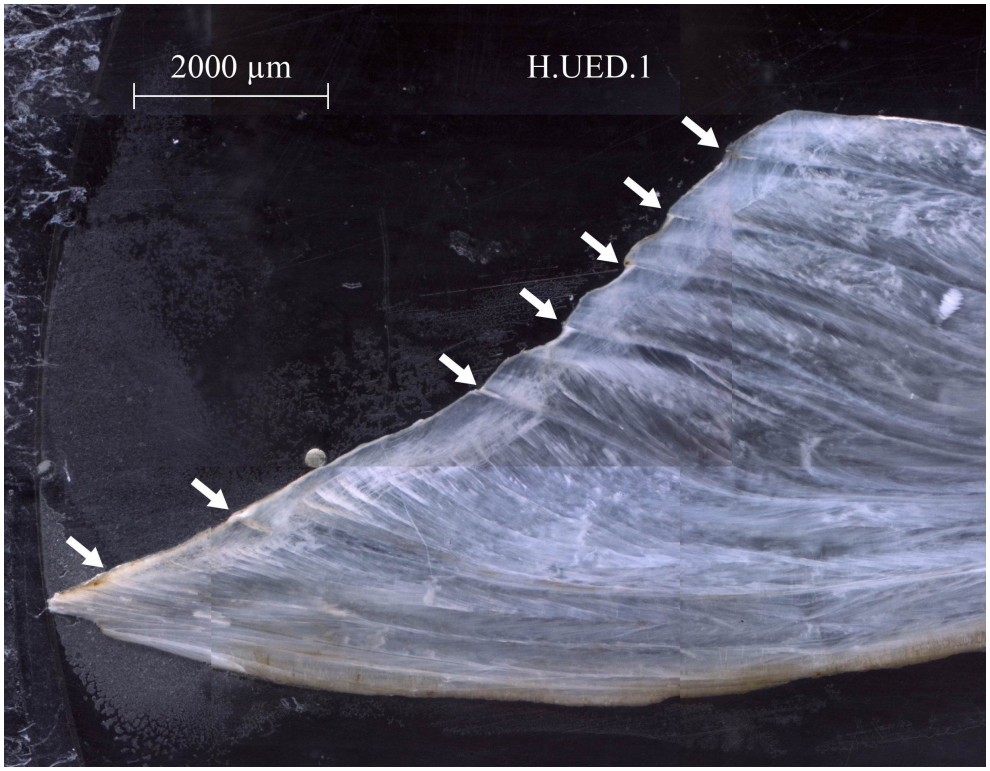


Figure 4.6: Thin section of H.UED.1 demonstrating the clear annual banding and seven lines. The edge shows a full year's growth: this has been categorised as a spring oyster.

Sample	Culture	Unsuccessful thin sections	Unreadable thin sections	Readable thin sections	Totals
1	TRB	1	13	10	24
2	EBK	5	5	19	29
3	EBK	1	4	15	20
POL	TRB	0	2	5	7
SQG	TRB	3	4	8	15
THR	TRB	0	4	8	12
THU	EBK	4	2	6	12
UEC	TRB	1	4	4	9
UED	TRB	0	5	4	9
Totals		**15**	**43**	**79**	**137**

Table 4.4: Successful and unsuccessful thin section figures.

4.6.2. Blind testing

All of the thin sections were examined with Eva Laurie, and an agreement was made on the season of death and age. In order to be confident that the readings could be replicated, a blind test was undertaken by Nicky Milner. All identification numbers on the thin section slides were obscured, and the two analyses were compared. For the 121 thin-sectioned shells, there was only disagreement with 29 shells. However, they were generally near, for instance winter/spring as opposed to spring. Where disagreement occurred all parties reviewed the thin sections, and after discussion a final agreement was reached on all readable shells, which were included in the final analysis.

4.6.3. Seasonality

The results of the oyster seasonal assessments are presented in Figures 4.7 and 4.8. A total of 79 oyster thin sections showed clear annual breaks in growth (Milner 2002a). The season of death results for the EBK samples (two, three and THU) are based on 40 successful thin sections, whereas the TRB samples (one, POL, SQG, THR, UEC and UED) are derived from 39. There was a clear and consistent signal for gathering in the spring for both cultures (Figure 4.7).

During the TRB the frequency of oysters collected in the spring is less than the EBK.

However there are a substantial number of oysters that were collected in the winter/spring prior to line formation. The variation in line formation may account for this difference. There was also a small peak of harvesting in the autumn/winter for both cultures. The only minor difference was the small number of oysters that have been assigned to the summer for the EBK. Overall, there is not a significant difference between the results for the EBK and the TRB with the exception of the small peak during the summer for the EBK.

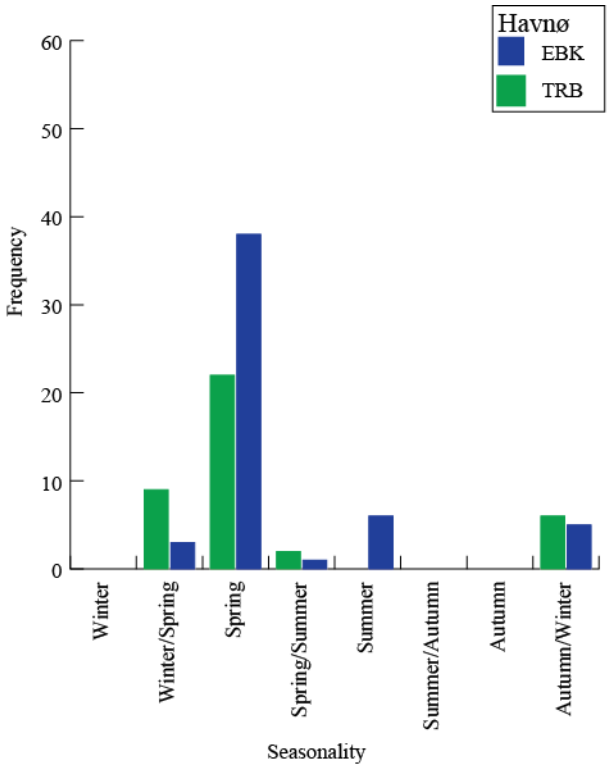


Figure 4.7: A histogram showing the seasonality of oyster gathering for the EBK and TRB cultures from Havnø.

To examine whether there are any differences in the collection practices within the kitchen midden the samples were also grouped according to the spatial distribution (Figure 4.8). Group one (n = 13) included the TRB samples (POL, UEC and UED) that were taken from the outlying squares to the north of the midden proper. These data demonstrated that harvesting was primarily undertaken during the spring (n = 5), followed by winter/spring (n = 4), autumn/winter (n = 3), and spring/summer (n = 1). Group two (n = 32) comprised of the samples that were extracted from the midden proper and included samples from the EBK (THU) and TRB (one, SQG, THR) cultures. Regardless of culture, the data demonstrated that oyster gathering was chiefly directed towards the spring (n = 19), followed by winter/spring (n = 8), autumn/winter (n = 3), and spring/summer (n = 2).

Group three (n = 34) was composed of EBK samples (two and three) that were removed from the south of the midden proper, closest to the palaeoshoreline. Similarly there was a clear signal for spring collection (n = 23), although oysters were also gathered during the summer (n = 6) and autumn/winter (n = 5). These data demonstrated that the only variation, in terms of summer collection, derived from group three to the south of the midden proper.

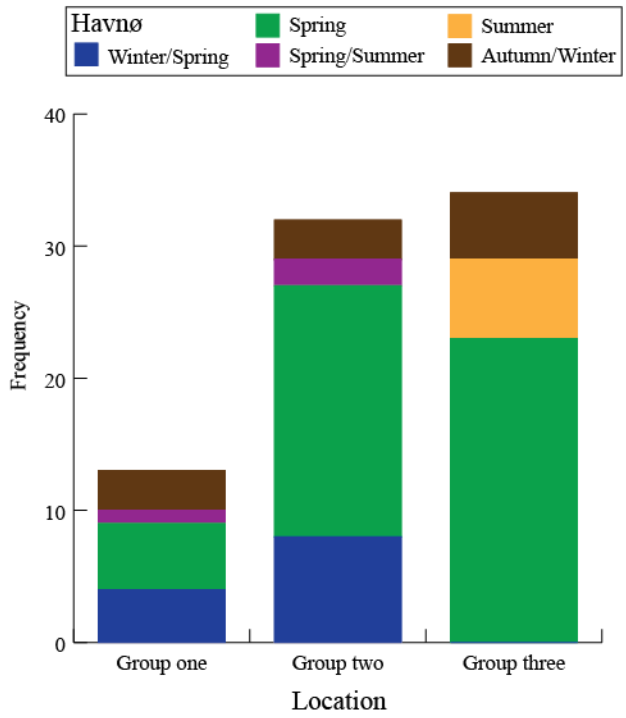


Figure 4.8: A histogram showing the seasonality of oyster gathering for each sample group that was spatially dependent.

Overall, it can be argued that there was not a clear shift in the season of exploitation across the Mesolithic-Neolithic transition at Havnø. The main season for both cultures was spring, which also includes the winter/spring and spring/summer assignations. There was a smaller quantity of gathering during the autumn/winter. The one difference between the two cultures was that oysters had been collected during the summer months in the EBK and had been deposited in the southern area of the kitchen midden: the EBK sample (THU) from the midden proper did not demonstrate summer gathering.

The question of course remains whether the observed patterning was consistent throughout the occupation of the kitchen midden, or whether a variety of collection events had occured. For example spring collection in one year, followed by autumn/winter during the next, and

early summer the year after.

4.6.4. Intensity of exploitation

4.6.4.1. Size and age

Two types of shell measurements were taken: hinge length in mm, and age in years. The oyster hinge length was measured because complete valves are not always consistently recovered in kitchen middens, whereas the hinge survives more frequently (Milner 2002a). There are however issues with both measurements in that where the tips of the hinges were broken the lengths may be slightly shorter and therefore the ages will be younger. In addition, since molluscs often grow unsymmetrically, the hinge length should not be taken as read (Milner 2002a). Regardless, it is possible to produce an overall representation of changing shell size by considering the mean for each sample group. In order to reduce ambiguity, sample groups with at least 10 shells were used.

In general it is clear that the oysters are larger in the EBK than the TRB (Figure 4.9). It can be seen that the oysters are largest at the base of the kitchen midden represented by sample three. There is a diminution in size further up in the midden sequence as demonstrated by sample two, and at the top, sample one, they are particularly small. Figure 4.10 presents the mean oyster hinge length per sample group according to location within the kitchen midden sequence. On average the oysters in the EBK were larger (11.4 ± 3.6 mm, n = 62) than those from the TRB (8.6 ± 1.8 mm, n = 69), suggesting a lesser-exploited population during the EBK.

In order to test whether this pattern for a reduction in the size of the oyster across the Neolithic transition is explained by the intensification of exploitation by humans or some sort of environmental change(s) in the marine biotope, the ages of the oysters have been determined by counting the annual lines, which were identified on the thin-sectioned shell slides.

If the oyster hinge lengths are compared with their age, it would appear that size

corresponds with age (Figure 4.11). It can be seen that the oysters deriving from the bottom of the midden sequence, which dates to the EBK, tend to be older when compared to those from the succeeding TRB layers at the top of the kitchen midden.

Figure 4.9: Sampled oysters from Havnø demonstrating the overall diminution in size from the bottom of the kitchen midden sequence, right, to the top, left (scale: 20 cm).

On the whole the largest and oldest oysters (sample Three) at the kitchen midden undoubtedly reflect a part of the initial depositional events. Under closer examination there is a notable difference in age between the oysters from sample Three (10.4 ± 2.9 years, n = 18), and the other sample groups. The other EBK samples (Two, THU) had similar mean lengths (10.9 ± 2.3 mm, n = 19, and 10.3 ± 4.4 mm, n = 12 respectively) to the TRB samples (UED, UEC, POL) from the north of the midden proper (10.5 ± 1.3 mm, n = 9, 9.6 ± 2.0 mm, n = 9, and 9.1 ± 2.0 mm, n = 7 respectively). The smallest shells were derived from the remaining TRB samples (One: 7.3 ± 1.4 mm, n = 17, THR: 8.8 ± 1.7 mm, n = 12, and SQG: 8.0 ± 1.3 mm, n = 15). This is particularly noteworthy in terms of the stratigraphy since they were removed from above some of the largest oysters (THU).

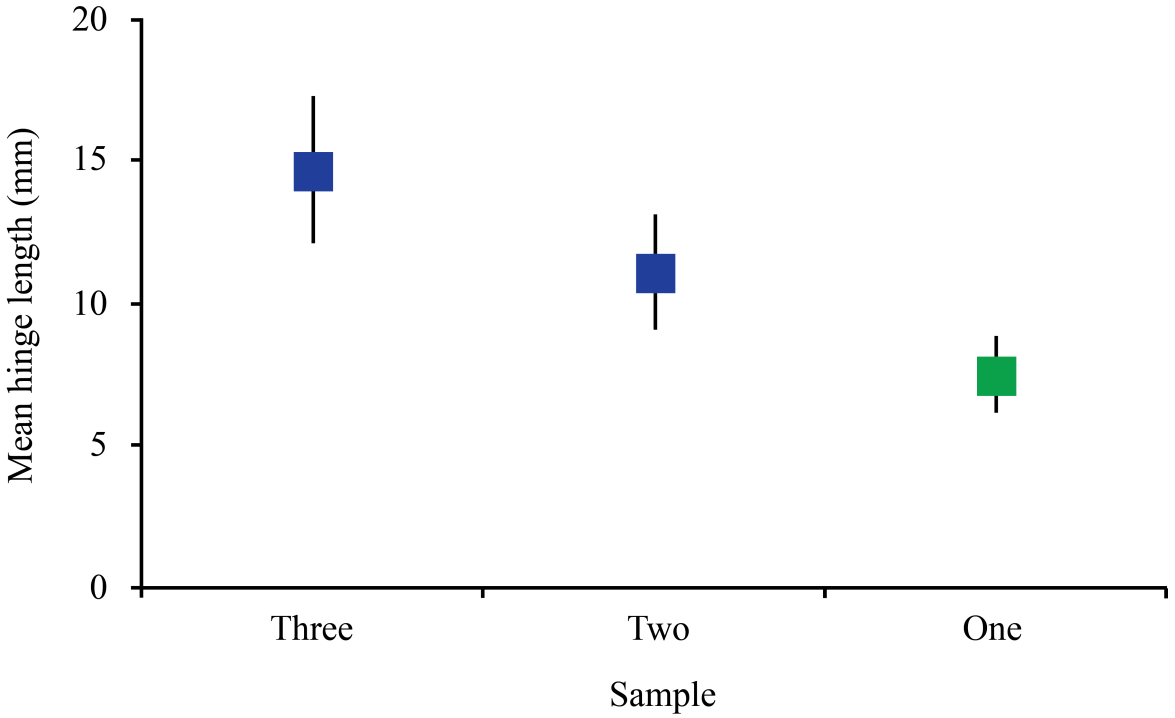


Figure 4.10: Mean hinge length and standard deviations (± 1σ) for oysters from Havnø, plotted from the bottom of the kitchen midden, Three, to the top, One. The size of each sample group was >10 shells: Three, n = 13, Two, n = 15, one, n = 14.

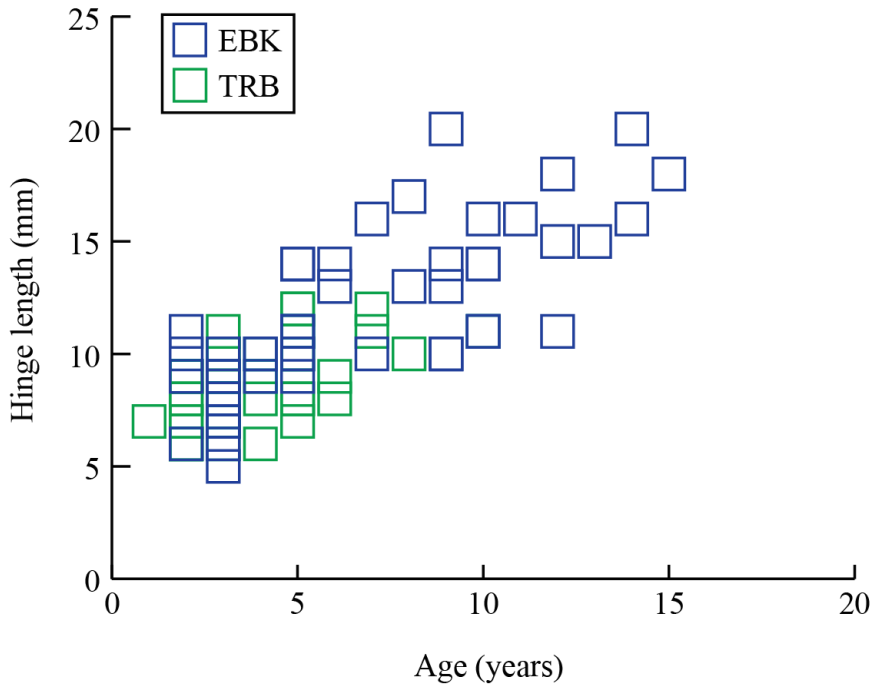


Figure 4.11: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from EBK (n = 63) and TRB (n = 50) oysters from Havnø. The scattergraph also includes the data from Milner (2002a).

4.7. Discussion

4.7.1. Introduction

The seasonality results from the Havnø kitchen midden appear to demonstrate a pattern of oyster gathering in at least two seasons during the EBK, and because this has been replicated in the three samples it suggests that this pattern is tangible. There may be a number of reasons for this pattern (Milner 2005), but one essential consideration is that oysters are more accessible at low tide. Thus, if the exploited shell bank off the Havnø island was situated in a particularly deep body of water (Milner 2005), it may have only been tidally accessible during the September and March equinoxes when the tide is at its lowest level. Equally oysters are considered to taste their best during the months of September through November that is in part due to the storage of glycogen and carbohydrate prior to a reduced availability of food (Sloan 1993). As such their flavour may have had a part to play in their exploitation (Milner 2005).

It should also be borne in mind that at the time of material deposition the Mariager Fjord would have been wider than the present with open access to the Kattegat Sea and so the possibility of sea ice can be ruled out. The mean temperature was also somewhat higher than the present during the EBK (Burman and Schmitz 2005).

The other significant pattern is that there appeared to be some summer gathering in one area of the kitchen midden during the EBK. Despite the small sample size, the patterning of the shells is coherent and convincing. What is particularly interesting here is that oysters are often viewed as being less palatable during the summer due to spawning. In addition, they pose a risk to health since they are susceptible to faster decomposition.

It is also interesting that there is no clear shift in the season of exploitation across the Mesolithic-Neolithic transition at Havnø. The TRB data similarly demonstrated that harvesting was principally undertaken during the spring with some autumn/winter gathering, which is different when compared with the data derived from contemporaneous archaeological sites (Milner 2002a, 2013; Milner and Laurie 2006, 2009; Laurie 2008).

Although there is some overlap in the size and age data between the EBK and TRB samples, there are also oysters from the EBK that are noticeably larger and older. This indicates that an unexploited population was harvested during the EBK, and the shells were deposited in the area that is now to the front of the kitchen midden as demonstrated by sample Three. As oysters continued to be exploited they were not able to ascertain an old age, consequently the mean age decreased. Although there is a degree of overlap in the mean size and age between some of the EBK and TRB samples, a more gradual decrease in size took place particularly in the midden proper. This change in size may be due to both the intensive exploitation by humans as well as changing environmental factors that can affect the natural shell banks as has been suggested for other kitchen middens (Milner and Laurie 2009). It is also interesting to note that Andersen (2008b) stated that there appeared to be an increase in the numbers of deformed oysters in the TRB layers when compared with the EBK layers, which may partly be explained by an intensification in the exploitation by humans and/or environmental factors.

4.7.2. Inter-site comparison

4.7.2.1. Introduction

Oyster shells from a further 15 Danish localities have been sectioned and analysed in terms of seasonality (Figure 4.12). The data for each site is presented in Appendix 3. The following section provides a short summary of the seasonality results for each sites organised by culture.

The first section presents the data from nine sites that are dated to the EBK. Unfortunately the majority of the samples are small, < 30 thin sections, and so interpretations should be treated with a degree of caution. However, a large sample was derived from the kitchen midden at Ertebølle. In addition, for both the sites in the Dyngby complex and the Ertebølle kitchen midden it is possible to examine patterns of seasonality spatially.

There are four stratified kitchen middens that span the EBK and TRB, which are similar to Havnø. These sites have been primarily sampled through the employment of column sampling. Thus, comparison of the results through the midden sequence provides an insight

over time. Consequently these kitchen middens tend to have larger sample sizes for assessment.

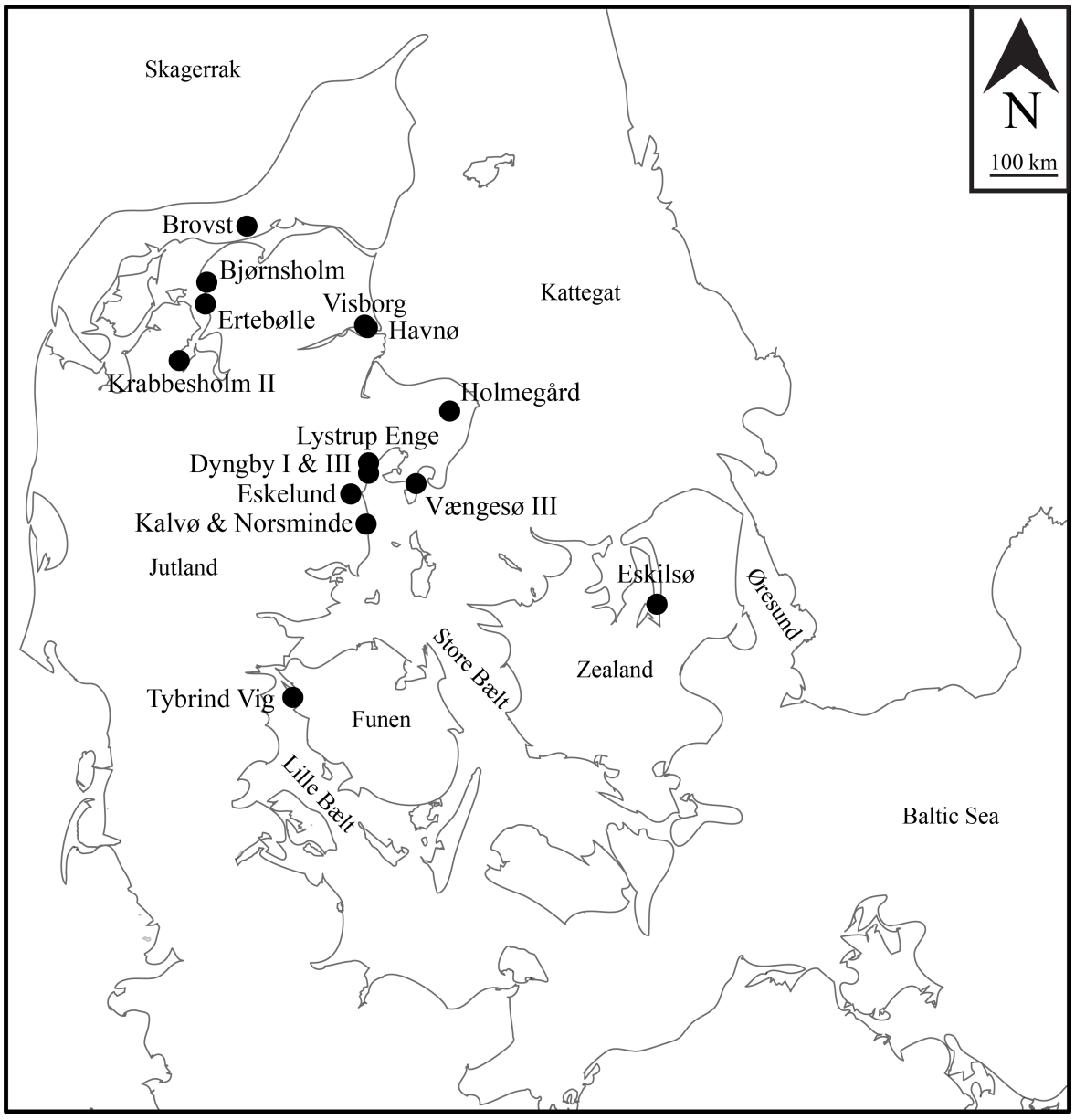


Figure 4.12: Map of Denmark showing all of the sites that have been analysed and included.

There are two kitchen middens that are dated exclusively to the Neolithic. The material culture, including the oysters from Visborg is dated to the TRB whereas Kalvø has been dated to the SGC. For the Visborg kitchen midden it was possible to conduct a detailed examination of seasonality spatially due to the sampling strategy undertaken.

4.7.2.2. EBK sites

It is extremely difficult to make explicit conclusions regarding the patterning from the nine sites that are dated to the EBK because eight of them have small sample sizes. However, there does appear to be some patterning with the majority of gathering taking place in the winter/spring, spring, and spring/summer periods for all sites (Figure 4.13). One oyster from each of the following sites at Dyngby I, Dyngby III and Vængesø III had been collected during the autumn/winter, possibly autumn. However, since the sample sizes are exceptionally small the interpretation is not confident. Likewise oysters from Dyngby I (n = 4), Ertebølle (n = 1), Eskelund (n = 1), Lystrup Enge (n = 2), and Tybrind Vig (n = 5) had been gathered during the summer but similarly the sample sizes are too small to make any substantiated interpretations.

Despite the small peak for winter/spring and summer collection events, the kitchen midden at Lystrup Enge is anomalous since only four shells were successfully sampled. Thus, without further analysis the data should be treated with caution. Tybrind Vig was the only submerged site sampled. Since it had a subtly different patterning it is difficult to ascertain whether the oysters are an accurate reflection of human exploitation. It is likely that they represented a combination of: (1) human discard, (2) the natural accumulation of shells on the seafloor, and (3) the remnants of a natural mollusc bank. It is considered that they are derived from the natural bank since very small oysters were recovered during the excavations, a number of which were paired, and a natural shell bank was identified in front of the site (Andersen 2013b).

For the kitchen midden at Ertebølle intra-site comparison was undertaken by comparing column sample J (Figure 4.14) to a random sample of oysters from the archives at Moesgård Museum. Unfortunately it was not possible to ascertain from where in the kitchen midden they are derived. However, the sample of 16 shells had a similar pattern to those sampled from column sample J (Figure 4.15).

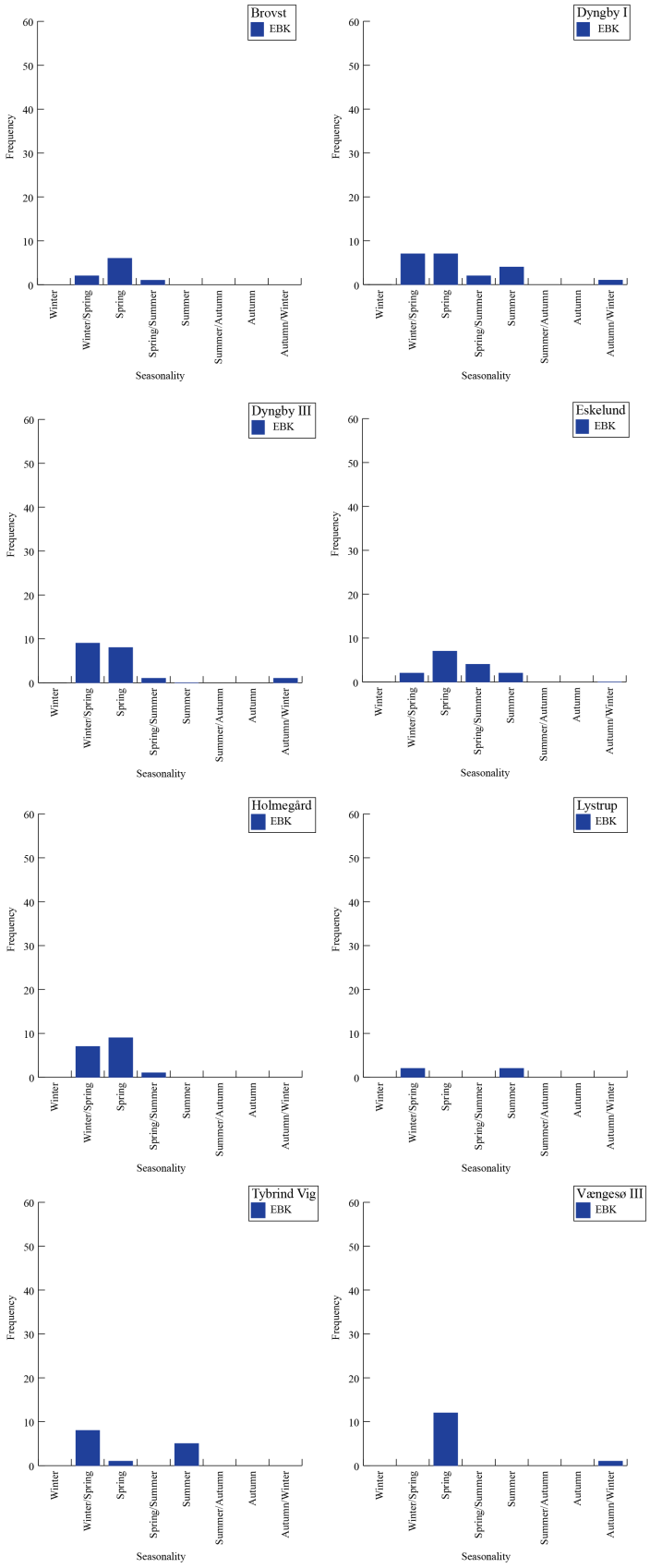


Figure 4.13: Histograms showing the seasonality of oyster gathering for the eight sites from which EBK oysters were sampled (Dyngby I, Eskelund and Lystrup are after Milner 2002a).

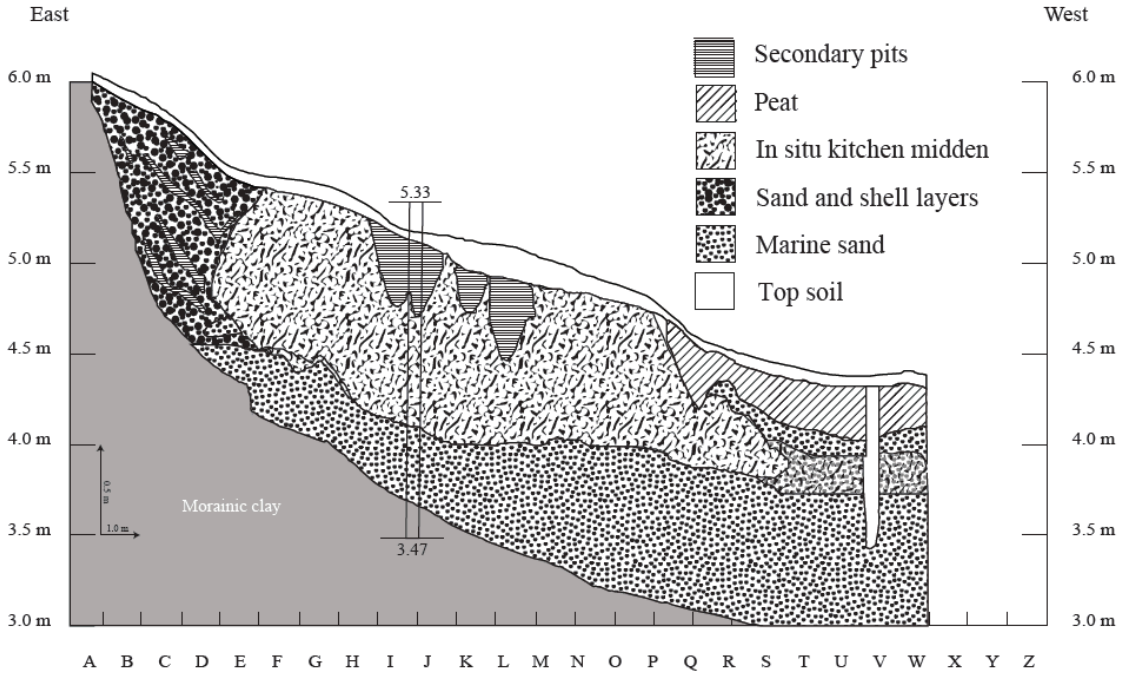


Figure 4.14: Southern section (E-W) through the Ertebølle kitchen midden. Redrawn and modified from Andersen and Johansen (1986, figure 10) and Petersen (1986, figure 3). Note column sample J covered the entire midden sequence.

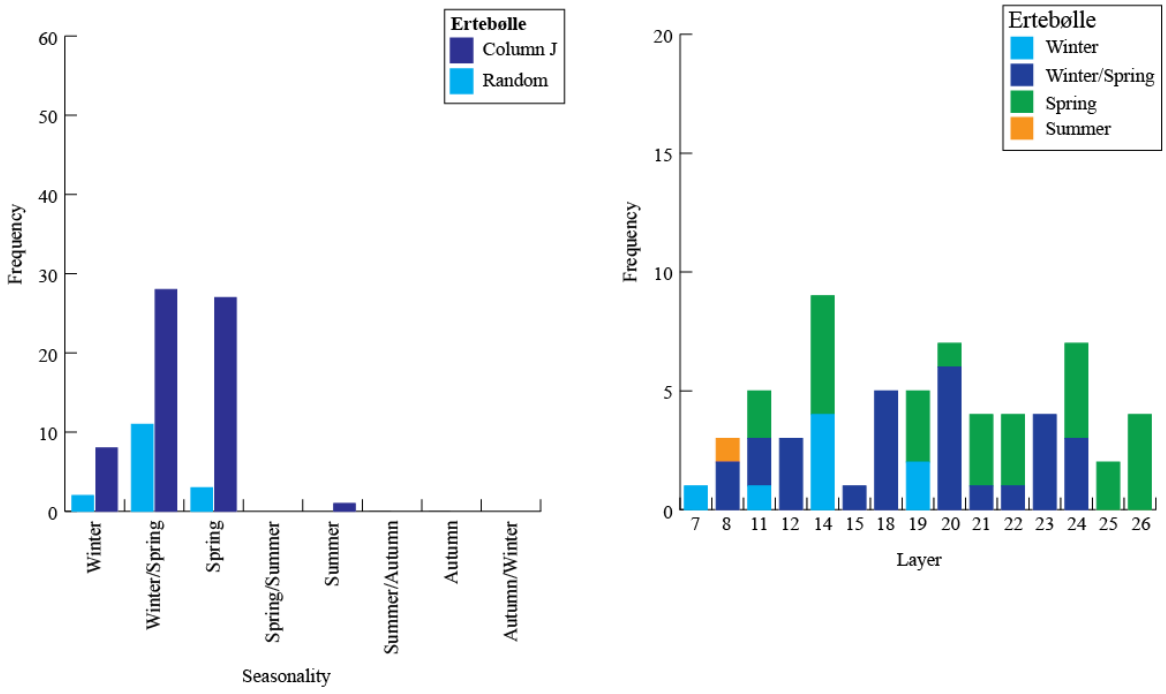


Figure 4.15: Ertebølle - (left) comparison of J and Random sample and (right) comparison of data through the layers of column sample J.

The samples from column sample J were examined in order to determine variation through time (Figure 4.15). Here there appeared to be a slight shift in patterning with spring gathering at the base of the midden sequence, represented by layers 25 and 26, which was followed by a smaller period of collection during winter/spring and spring from layers 24 to 20. From layers 19 towards the top of the midden sequence (layer seven) collection was similar although there were periods of slightly earlier gathering that were undertaken during the winter and winter/spring.

Similarly, for the two sites sampled from the Dyngby complex it was possible to assess spatial patterning. At Dyngby I each sample produced different results (Figure 4.16). While sample one demonstrated explicit collection events during the winter/spring and spring, samples two and three had a tendency toward spring/summer and summer harvesting. Predictably the random sample demonstrated gathering throughout the majority of the year. At Dyngby III samples D3C and D3D demonstrated winter/spring and spring, whereas the shells from sample D3A had been solely harvested during the spring (Figure 4.16). Spatially it would appear that the general collection events did not differ significantly besides the spring/summer and autumn/winter gathering to the south western part of the site (Figure 4.17).

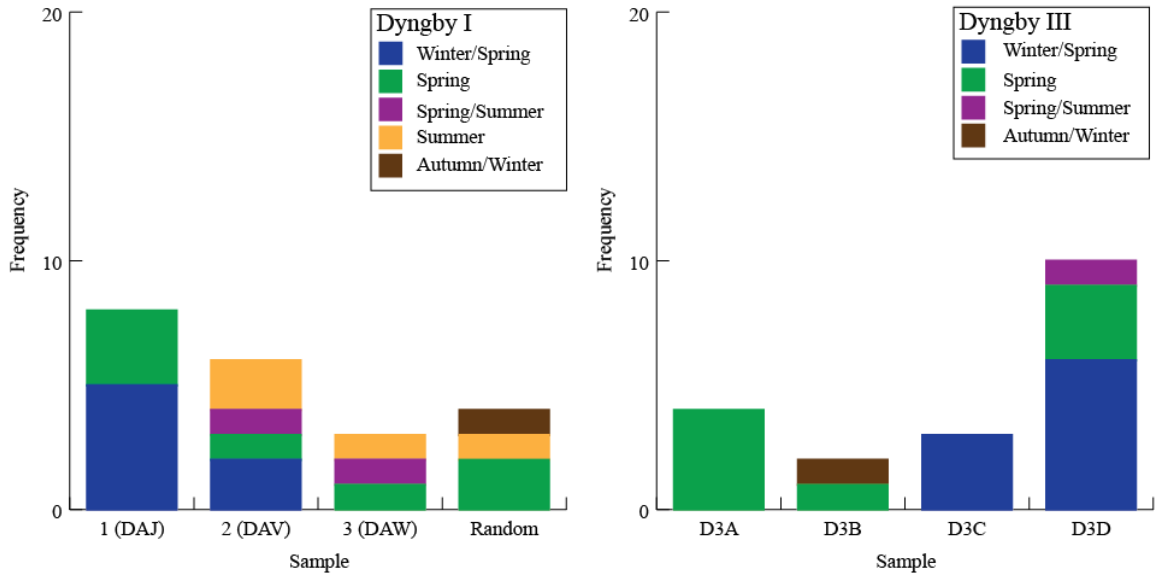


Figure 4.16: Dyngby I and Dyngby III comparison of results.

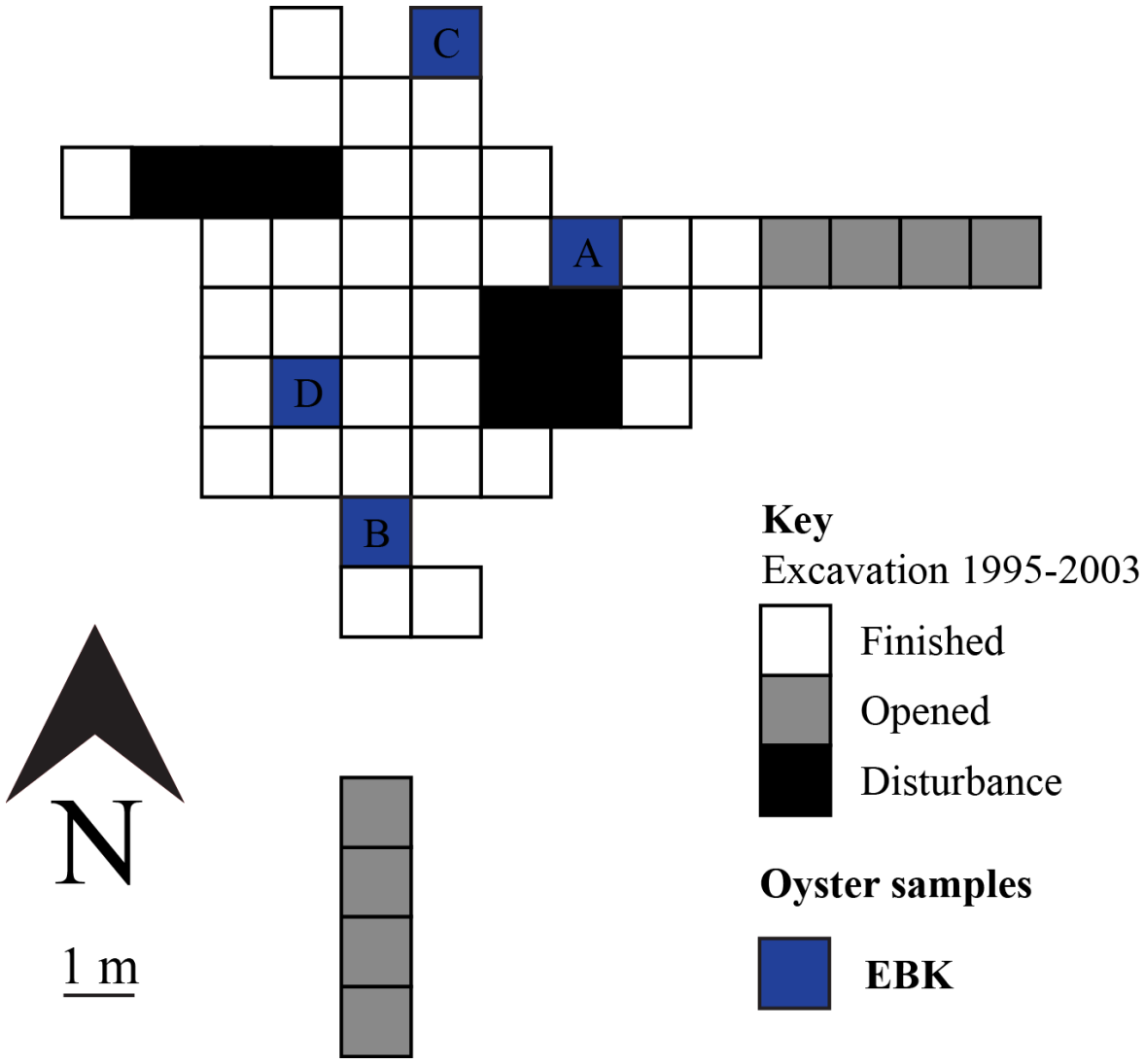


Figure 4.17: The full extent of the Dyngby III excavations and the oyster sample locations in this study.

In sum there is some subtle variation throughout the EBK across the nine sites sampled. However, the general patterning demonstrated a peak gathering around the springtime, which included winter/spring and spring/summer as was detected at the Havnø kitchen midden. Some variation across space and time occurred when the data were assessed.

4.7.2.3. Stratified EBK and TRB kitchen middens

The results from the four stratified kitchen middens appeared to show some startling regional differences. During the EBK at the four kitchen middens oysters were primarily gathered during the winter/spring and spring (Figure 4.18). Unfortunately the smaller

sample size from Krabbesholm II limits discussion. For the three other kitchen middens there is additional gathering on a comparatively small scale through spring/summer and summer, and at Bjørnsholm and Eskilsø collection events continued into the autumn, autumn/winter and winter. This overall picture is very similar to the EBK sites presented above.

In terms of the TRB layers at the kitchen middens, there was a similar patterning with a peak of gathering during the winter/spring and spring. Although the sample size from Eskilsø is small (n = 16), surprisingly collection events throughout the year were not represented. For Bjørnsholm and Norsminde there was some harvesting during the spring/summer and summer. However, Krabbesholm II was prominent since gathering was undertaken during all of the seasons, including the summer, autumn/winter and winter to a significant degree.

For intra-site comparison at Eskilsø samples were taken from four distinctive areas throughout the kitchen midden sequence (Figure 4.19). These samples have been disaggregated according the culture, and are shown in Figure 4.20. Despite the spatial distribution the patterning for the different EBK samples had considerable similarity. The six samples demonstrated that harvesting was principally undertaken during the winter/spring and spring. However, gathering during the other seasons of the year had also been carried out including the spring/summer and summer.

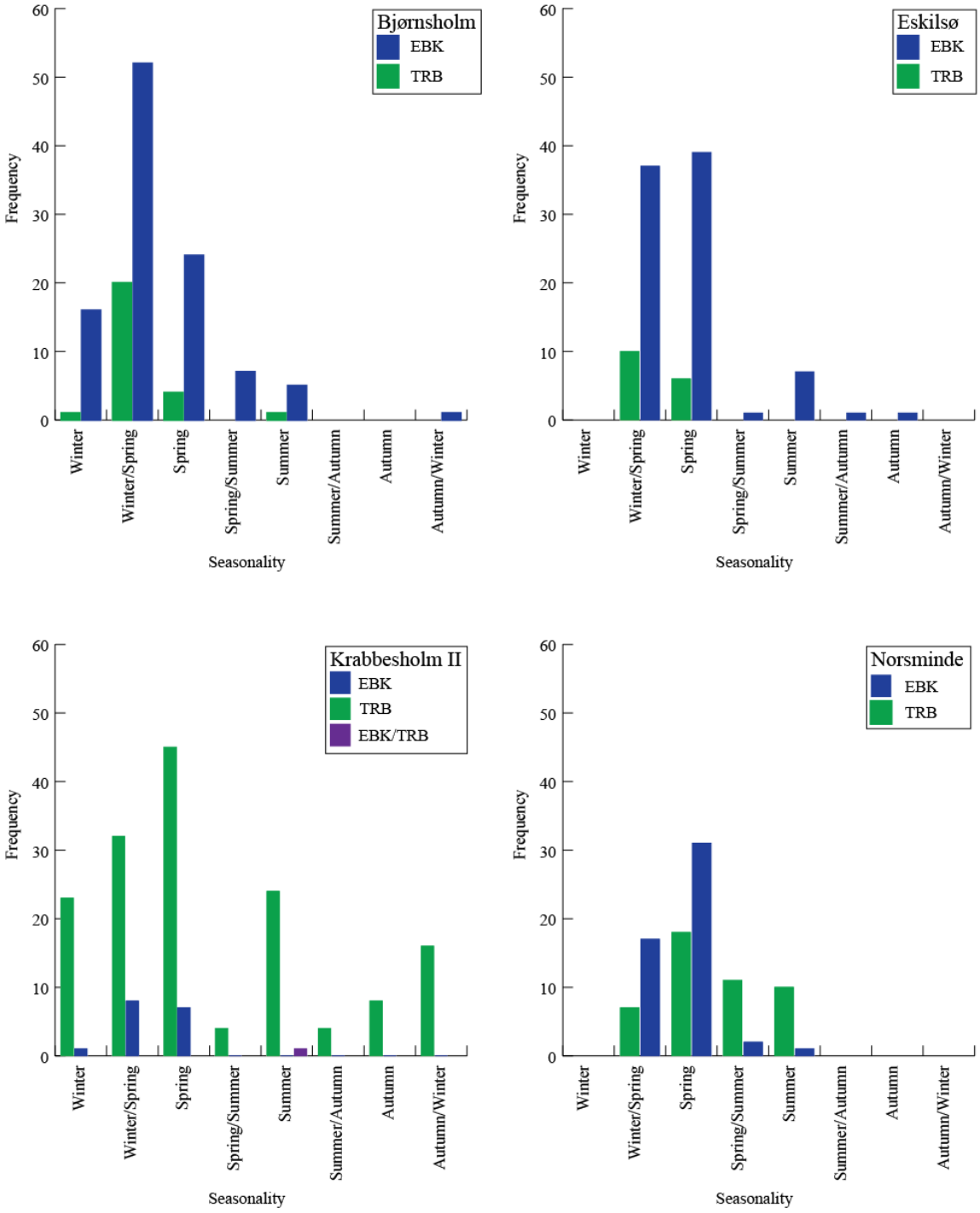


Figure 4.18: Histograms of oyster seasonality for the stratified kitchen middens (Krabbesholm II and Norsminde are partly after Milner 2001a, Milner 2002a, 2013; Milner and Laurie 2006, 2009).

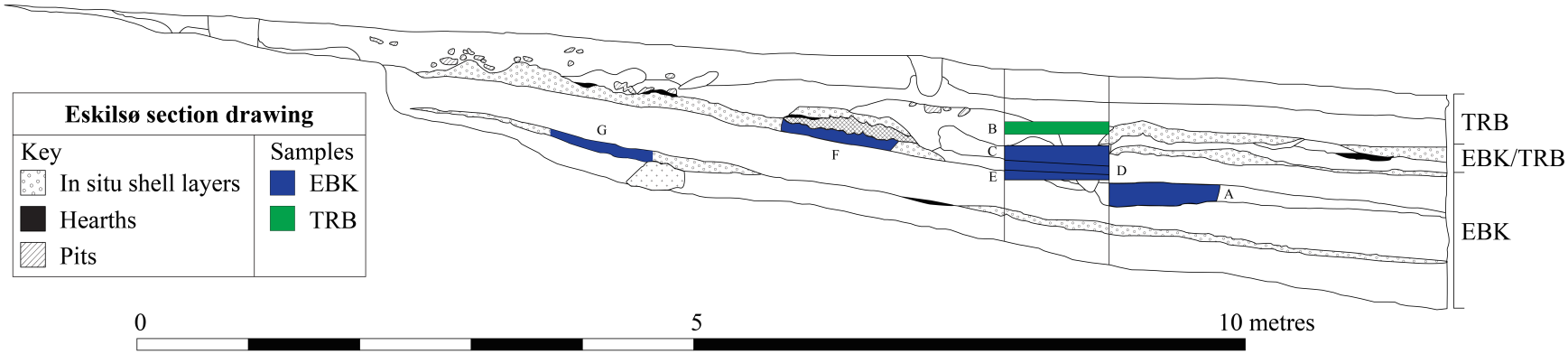


Figure 4.19: Section through the Eskilsø kitchen midden. Redrawn and modified from the original drawing by Sørensen (personal communication to Nicky Milner 2001). Note the location of sample B that is stratified above samples C, D, and E.

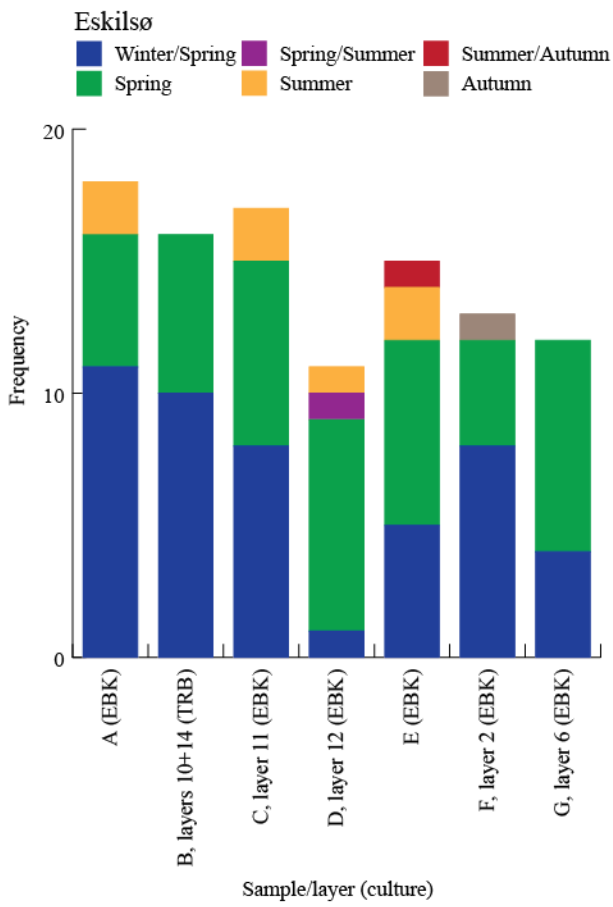


Figure 4.20: A histogram showing the seasonality of oyster gathering that has been disaggregated according to sample/layer from Eskilsø.

In order to assess diachronic variation for Norsminde, the samples have similarly been disaggregated according to layer for both the EBK and TRB samples (Figure 4.21). The data for the EBK layers are strikingly uniform and demonstrate that the majority of the oysters had been collected during the winter/spring and spring. In addition, some oysters had been gathered during the spring/summer and summer. Interestingly, this pattern continued in layers six and five of the TRB kitchen midden before an explicit shift towards spring/summer and summer harvesting in layers four to one.

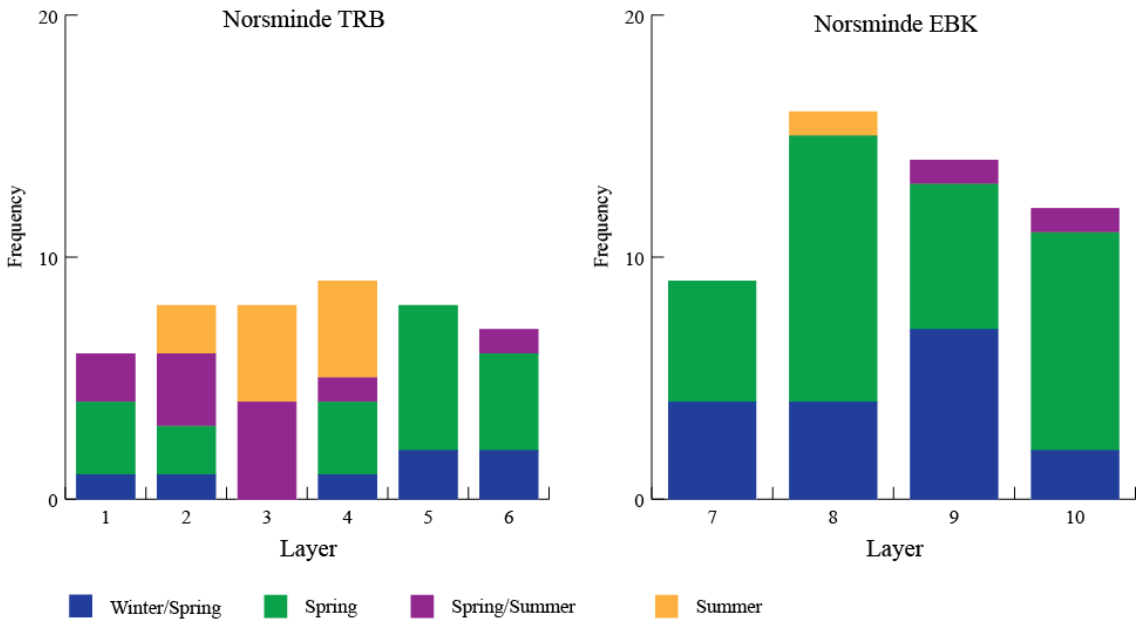


Figure 4.21: Histograms showing the EBK (right) and TRB (left) seasonality of oyster gathering that has been disaggregated according to layer from Norsminde (after Milner 2002a, 2013; Milner and Laurie 2009).

4.7.2.4. Neolithic samples

For the two Neolithic kitchen middens samples there was a clear patterning of winter/spring and spring gathering (Figure 4.22). Kalvø also demonstrated that harvesting was undertaken during the autumn and autumn/winter, which has been witnessed at a number of sites. On the other hand Visborg had evidence for collection events throughout the year except for summer/autumn. Comparison between the different sections throughout Visborg revealed subtle differences in the collection events (Figure 4.23). In general, the five sample groups demonstrated that oyster gathering was principally undertaken during the winter/spring, spring, and winter. However gathering was also carried out during the spring/summer at four of the five-sampled locations, whereas collection during the summer and autumn/winter took place at two of the sampled locations respectively.

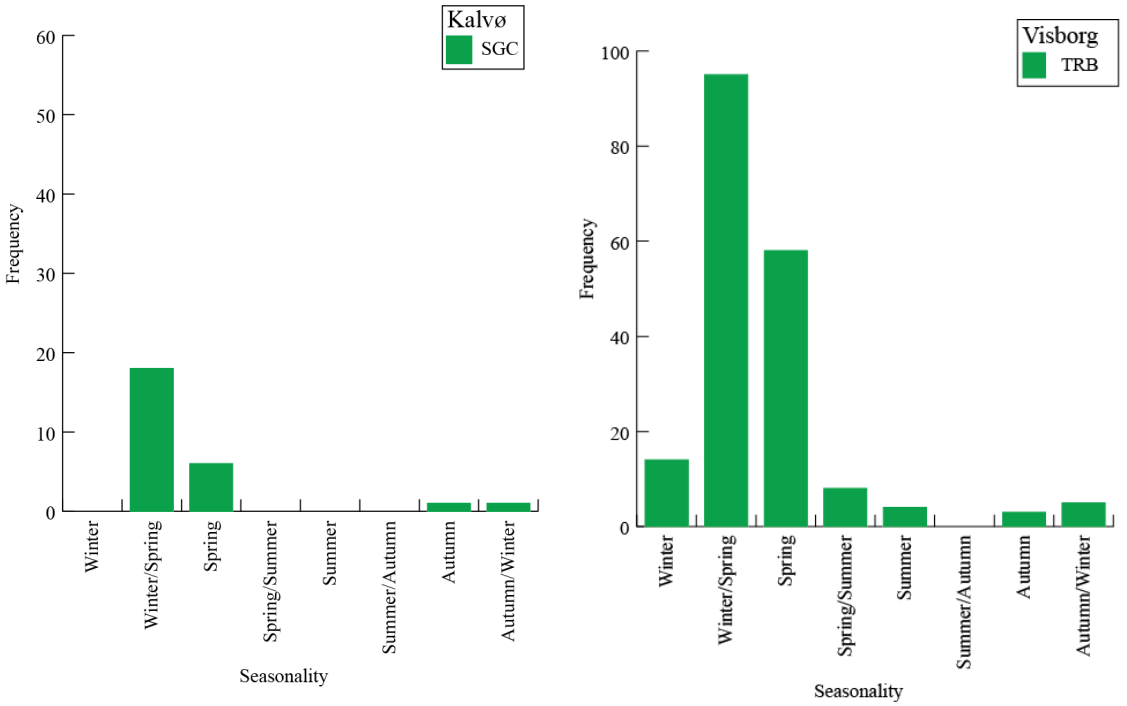


Figure 4.22: Histograms of oyster harvesting for the Kalvø and Visborg kitchen middens (Visborg is partly after Milner 2002a).

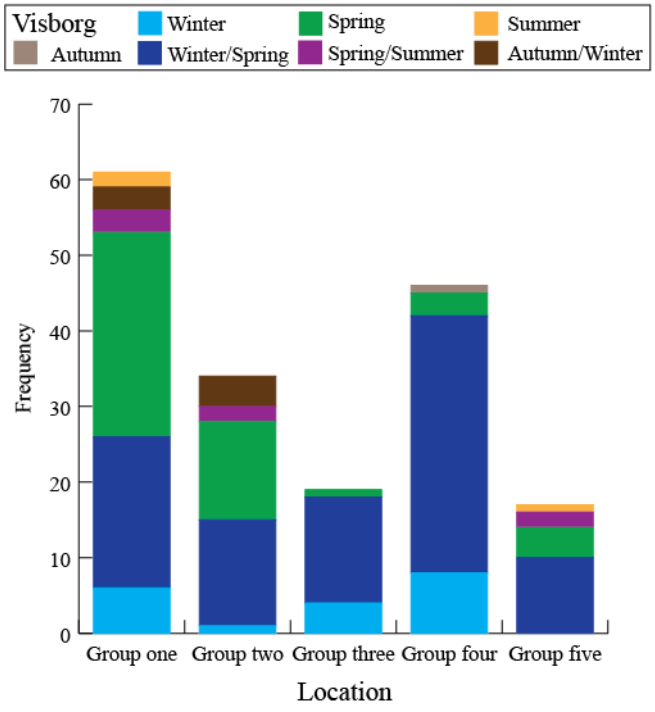


Figure 4.23: A histogram showing the seasonality of oyster gathering that has been disaggregated according to sample group from Visborg.

4.7.2.5. Overview of seasonality assessments

Including previous studies, a total of 1612 archaeological oysters have been sampled from 16 Danish sites (Appendix 3). Every site had differences but there were underlying patterns, for instance oyster collection was primarily undertaken during the winter/spring or spring regardless of period or culture. In addition, some sites also demonstrated collection events that were carried out during the summer or autumn or both, but the number of oysters was always fewer when compared to those that had been harvested during the spring. During the TRB there appeared to be more variability. While gathering appeared to be restricted towards certain periods of the year at the Havnø and Norsminde kitchen middens, collection was undertaken throughout the majority of the year at the Krabbesholm II and Visborg kitchen middens. While there may have been sampling issues, this is unlikely since both column (Krabbesholm II, Norsminde) and spatial (Havnø, Visborg) sampling was undertaken. Although the majority of the stratified kitchen middens exhibited a subtle change in the collection events across the Mesolithic-Neolithic transition, this was not the case for the Havnø kitchen midden.

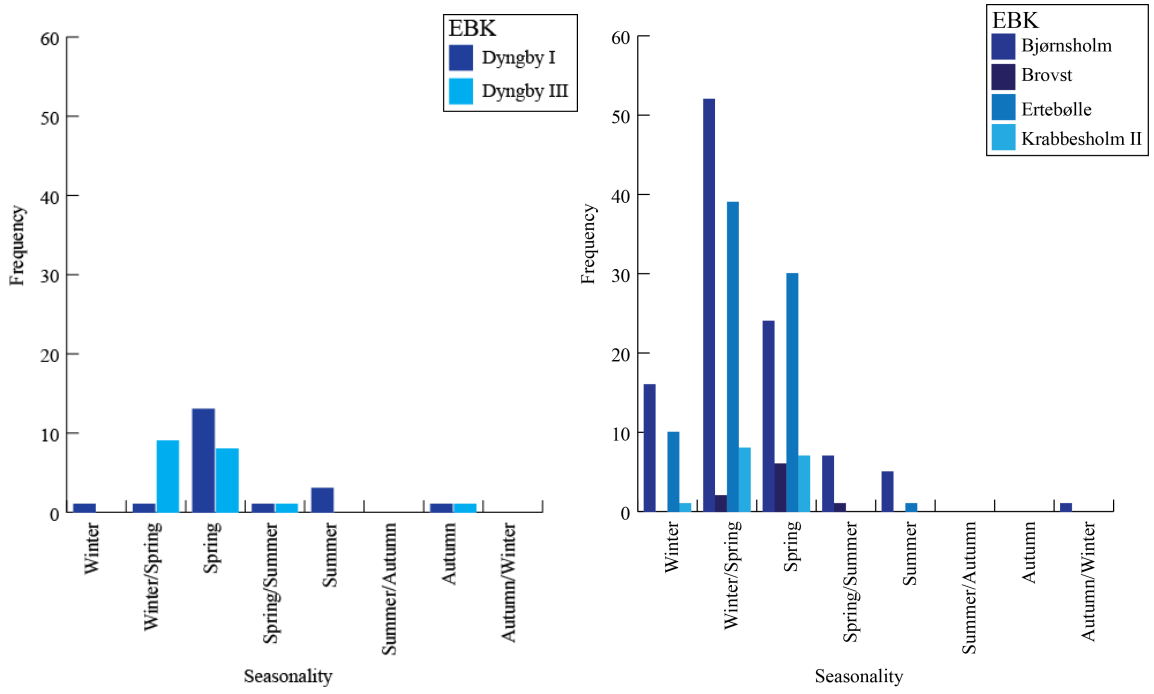
4.7.2.6. Regional variation

In order to explore regional seasonality variation the sites have been grouped according to their location and relative age (Appendix 3). Thus, the kitchen midden at Dyngby I and the shell-bearing site at Dyngby III are grouped to form the Dyngby complex. Unfortunately it is not possible to examine collection events for the TRB since both sites are dated to the EBK. The Limfjord has one of the highest concentrations of kitchen middens in Denmark, which have been intensively investigated since the beginning of the 20th century (Andersen 2000a, 2004a, 2007, 2008a; Madsen *et al*. 1900). Thus, comparison is possible between four of the most important kitchen middens: Bjørnsholm, Brovst, Ertebølle and Krabbesholm II. Together they form the Limfjord group. The samples from the Brovst and Ertebølle kitchen middens are solely dated to the EBK, however the TRB dataset is represented by two stratified kitchen middens, Bjørnsholm and Krabbesholm II. The Mariager Fjord group comprised the two kitchen middens at Havnø and Visborg. Since there was a dearth of EBK layers at the Visborg kitchen midden only the TRB data will be discussed. The kitchen middens at Kalvø and Norsminde represented the Norsminde Fjord

group. Likewise only the Neolithic data will be examined since the EBK dataset is restricted to the Norsminde kitchen midden. Kalvø is of particular interest because it is the only kitchen midden in southern Scandinavia that has been dated to the SGC (Andersen 1983).

Although there was an explicit patterning of collection during the spring and winter/spring for both of the Dyngby sites, oysters were also collected throughout other seasons and periods (Figure 4.24). Despite the similarity between both sites the small sample sizes limit the degree of discussion.

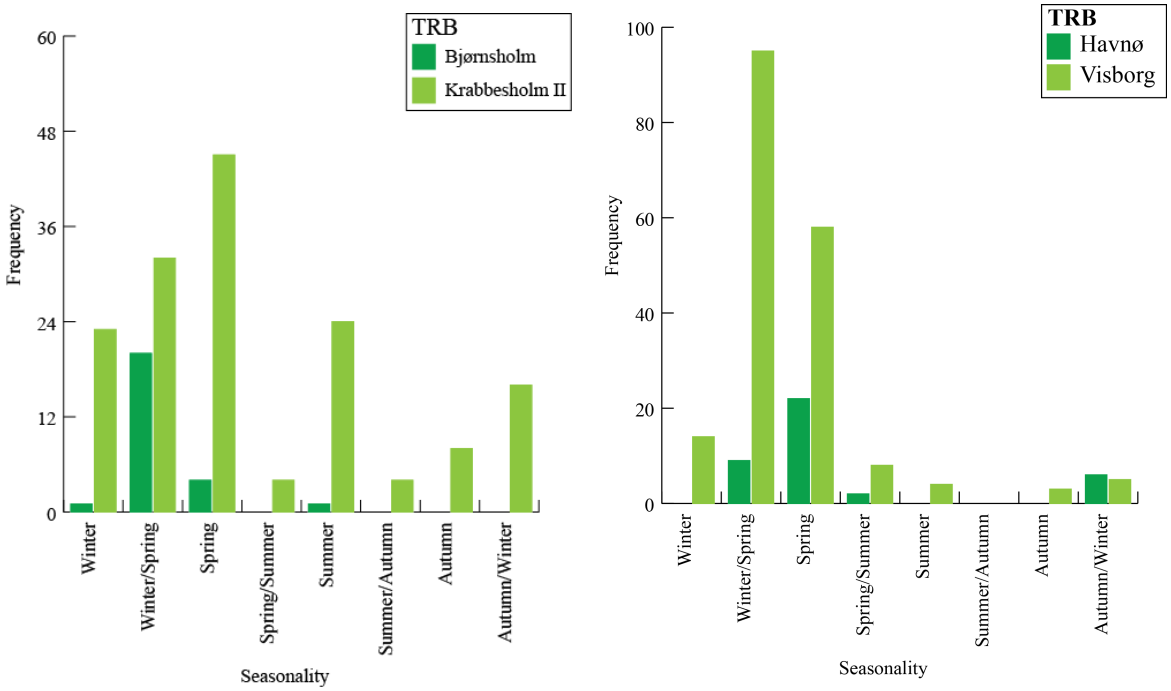
During the EBK in the Limfjord it can be seen that harvesting was chiefly directed towards the winter/spring, spring, and winter (Figure 4.25). The data from the four kitchen middens is essentially identical besides a small collection event during the summer at both Bjørnsholm and Ertebølle, which is similar to the Dyngby complex. However, as previously noted the Brovst and Krabbesholm II sample sizes were smaller.



Figures 4.24 (left) and 4.25 (right): Histograms showing the seasonality of oyster gathering for the Dyngby complex (left), and the EBK samples from the four kitchen middens in the Limfjord (right) (Dyngby I after Milner 2002a, Krabbesholm II after Laurie 2008; Milner 2001a, 2013; Milner and Laurie 2006).

The dataset for the Limfjord during the TRB is restricted to the two stratified kitchen middens, Bjørnsholm and Krabbesholm II (Figure 4.26). The collection events from Bjørnsholm mirror those from the EBK layers at the stratified kitchen middens with a pronounced patterning of oyster gathering during the winter/spring. While the Krabbesholm II data had a similar patterning, harvesting throughout the year was intensively undertaken.

The TRB layers at Havnø and Visborg were in essence identical with an explicit patterning of collection during the winter/spring, spring, winter, and spring/summer (Figure 4.27). Collection throughout the course of the year can also be envisaged at both kitchen middens but on a notably reduced scale when compared to the Limfjord.



Figures 4.26 (left) and 4.27 (right): Histograms showing the seasonality of oyster gathering for two stratified kitchen middens in the Limfjord (left), and the TRB samples from the Havnø and Visborg kitchen middens in the Mariager Fjord (right) (Krabbesholm II after Laurie 2008; Milner 2001a, 2013; Milner and Laurie 2006, Visborg partly after Milner 2002a).

During the TRB in the Norsminde Fjord the harvesting of oysters was almost spread out equally throughout the year as demonstrated by the Norsminde kitchen midden (Figure 4.28). This patterning was very similar to Krabbesholm in the Limfjord, and to a lesser

extent Visborg in the Mariager Fjord. In comparison the collection events for the SGC as demonstrated by the Kalvø kitchen midden were very similar to the majority of the shells deriving from EBK contexts, including Norsminde.

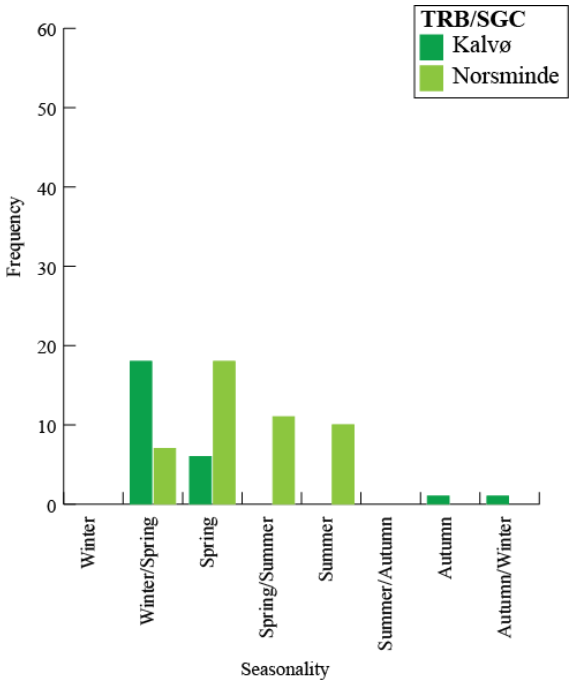


Figure 4.28: A histogram showing the seasonality of oyster gathering for the two kitchen middens in the Norsminde Fjord (Norsminde after Milner 2002a).

4.7.3. Size and age

4.7.3.1. Introduction

The size and age data will be discussed in detail for the following kitchen middens Bjørnsholm, Ertebølle, Eskilsø, Krabbesholm II, Norsminde and Visborg for which >100 oysters were sampled. For these sites samples with more than 10 shells will only be presented in order to make more meaningful comparisons between either layers from columns or samples.

In a similar manner, the first section presents the data for the Ertebølle kitchen midden since the other eight EBK sites had small sample sizes. For Ertebølle comparison is made between the randomly sampled shells and column sample J. This will be followed by the four stratified kitchen middens that span the EBK and TRB, which are similar to Havnø. Since column samples were employed at Bjørnsholm, Krabbesholm II and Norsminde

diachronic change through time will be examined. Unfortunately the sample size for the column sample from Bjørnsholm varied considerably. Consequently only two layers will be discussed. On the other hand the individual layers of the Krabbesholm II and Norsminde column samples were extensively sampled. Ten of the 16 layers from Krabbesholm II, and nine of the 10 layers from Norsminde will be presented. For Eskilsø it was possible to examine diachronic change through time given the sampling strategy undertaken. The Visborg kitchen midden is the only site representing the TRB. However, the large sample size made it possible to examine diachronic change for one section as well as spatial variability.

4.7.3.2. The Ertebølle kitchen midden

In general the oysters from Ertebølle were exceptionally small as demonstrated by their mean hinge lengths (5.2 ± 2.1 mm, n = 139). Figure 4.29 presents the mean shell hinge length for the randomly selected oysters (VX), as well as five of the 16 layers from column J that had sample sizes >10. It can be seen that the randomly selected oysters had an identical hinge length (6.0 ± 2.2 mm, n = 27) when compared to those from near to the bottom of the midden sequence as demonstrated by layer 24 (6.0 ± 2.5 mm, n = 17). Overall the oysters were marginally larger in the lower layers of column J. There was a subtle diminution in size between layers 24 and 20, which was followed by a slight increase between layers 20 and 14. The largest oysters were observed in layer 15 (6.3 ± 2.9 mm, n = 7), whereas the smallest was derived from layer 10 (3.0 mm). However, this should not be taken as read since it was only possible to measure one shell from this layer. It is unlikely that these data support the notion for an unexploited population.

Interestingly a change in the species composition throughout the midden sequence was identified by Petersen (1986). The analysis demonstrated that while oyster was the principal component throughout column J, a lesser-marked cockle peak was observed from layers 12 to six. This peak has been dated from ca. 4460-4040 cal BC (K-4314, 5430 ± 95 B.P.), (Andersen 2000a; Andersen and Johansen 1986) and corresponded to the steady reduction in the size of the oysters from layers 14 through seven. Thus, it is entirely plausible that the cockle was favoured to the exclusion or reduction in the exploitation of oysters.

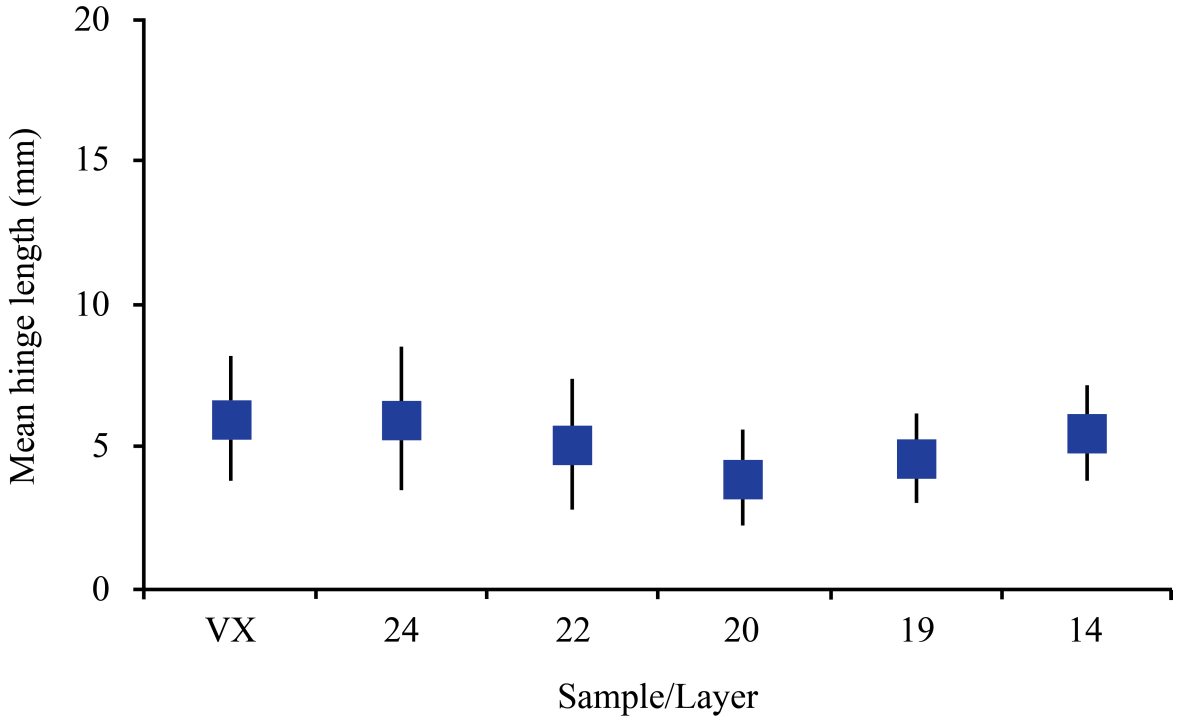


Figure 4.29: Mean hinge length and standard deviations (± 1σ) for oysters from Ertebølle, plotted from lower down in the midden sequence, 24, to higher up, 14. The size of each sample group was >10 shells: VX, n = 27, 24, n = 17, 22, n = 10, 20, n = 10, 19, n = 11, 14, n = 10.

Comparison between age and estimated shell length (cm), which was calculated by conversion of the hinge lengths (Milner 2013), demonstrated a positive correlation (Figure 4.30). Overall the oysters from Ertebølle were particularly young. They had a mean age of 2.4 ± 1.1 years (n = 94). When the data are disaggregated the randomly selected shells were slightly larger (2.6 ± 0.8 years, n = 18) than the mean for the kitchen midden as a whole. In a similar manner to the oyster hinge lengths, age fluctuated over time in column sample J despite the small sample size.

The oysters in the lower layers of column J tended to be older compared to those higher up in the midden sequence. In general the shells in layers 26 and 25 were oldest (4.0 ± 1.4 years, n = 4, and 4.0 years, n = 1 respectively). There was a slight reduction in layers 24 (2.9 ± 2.1 years, n = 9) and 23 (1.8 ± 1.3 years, n = 5), before an increase in layer 22 (2.3 ± 0.9 years, n = 8). Then there was a second reduction in layer 21 (1.3 ± 0.5 years, n = 4), which was followed by an increase in layers 20 (2.0 ± 0.6 years, n = 7) and 19 (2.3 ± 0.3

years, *n* = 5). A third reduction was observed in layer 18 (2.0 ± 0.7 years, *n* = 5) before a noticeable increase in layer 15 (3.5 ± 0.7 years, *n* = 2). There was a steady reduction from layer 14 (2.9 ± 0.6, *n* = 10) to layer 11 (1.8 ± 0.8 years, *n* = 6). Unfortunately the data from layers 10 and seven were based on one calculation each, and are essentially meaningless. There was a final increase in layer eight (3.0 ± 1.7 years, *n* = 3).

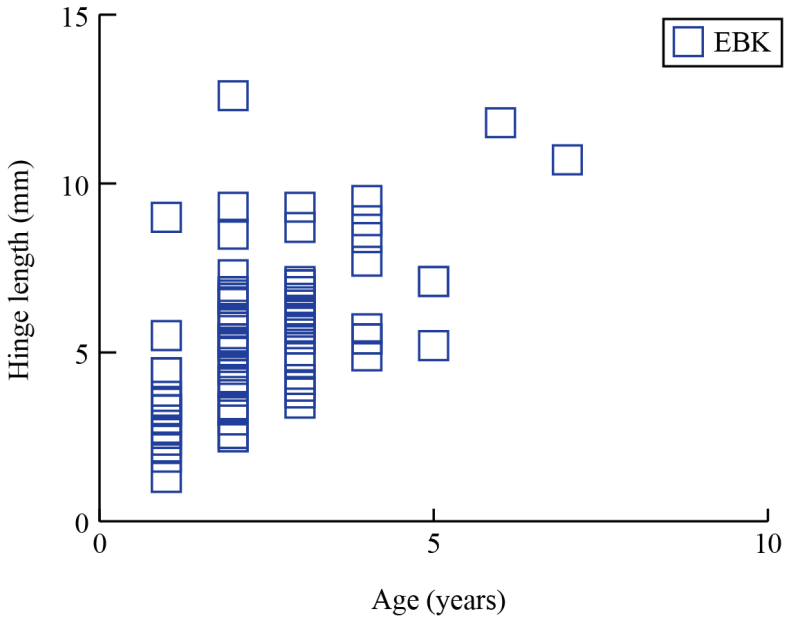


Figure 4.30: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from Ertebølle (n = 93).

The modest temporal fluctuation in size and age probably represents numerous environmental factors, and not increased exploitation of the natural oyster bed, i.e. the age structure was being depressed although the size is near constant. It is most probable that the oysters experienced periods of increased growth over the course of material deposition, and oscillations in the primary production of the Limfjord took place. Interestingly, the near constant environmental conditions are unlikely to have only affected those oysters deposited in the area where column J was excavated since the randomly selected shells were essentially identical. If other areas of the kitchen midden had been samples there may have been evidence in favour of overexploitation. On the other hand the degree of fluctuation could conceivably represent a reduction in the intensity of gathering that is allowing the natural oyster population to recover, or that the area where column J was located had accumulated quickly.

4.7.3.3. Stratified EBK and TRB kitchen middens

On average the oysters were marginally larger (7.9 ± 6.0 mm, *n* = 173) in the EBK than the TRB (7.2 ± 2.1 mm, *n* = 53) at the Bjørnsholm kitchen midden. Figure 4.31 presents the mean oyster hinge length per sample in descending order. Despite the sites proximity to the Ertebølle kitchen midden regardless of period they were noticeably larger. A subtle diminution in size was also observed throughout the midden sequence of column D2 despite the small sample size (Figure 4.32). The oysters were largest further down (layers six and seven), and higher up (layer two and sample GAS) they were very small.

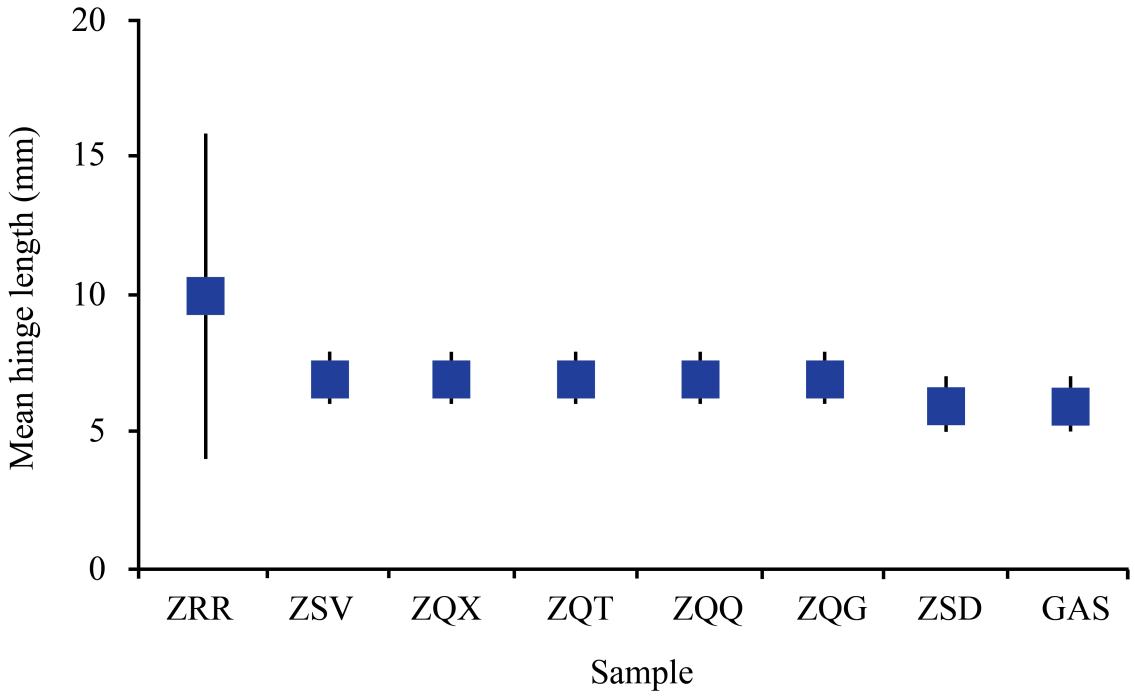


Figure 4.31: Mean hinge length and standard deviations (± 1σ) for the EBK oysters from Bjørnsholm, plotted in descending order. The size of each sample group was >10 shells: ZRR, n = 21, ZSV, n = 11, ZQX, n = 21, ZQT, n = 25, ZQQ, n = 26, ZQG, n = 11, ZSD, n = 12, GAS, n = 11.

Likewise age and oyster shell length had a positive correlation (Figure 4.33). Surprisingly the oysters dated to the TRB were older (3.1 ± 2.1 years, *n* = 24) than those from the EBK (2.7 ± 1.4 years, *n* = 101). This was suggestive of an increase in the age structure of the natural population related to either a reduction in the intensity of gathering or environmental factors. The primarily production in the Bjørnsholm Fjord may have been

depressed, as such the oysters were growing at a similar rate regardless of period but they are achieving an older age during the TRB.

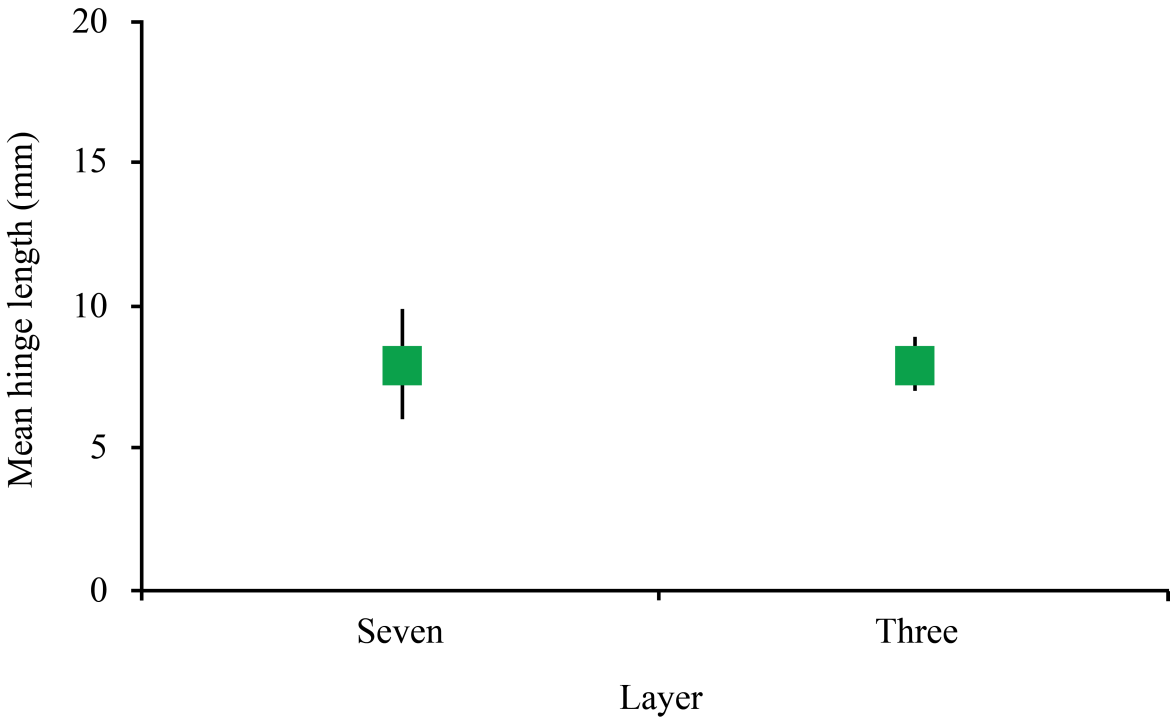


Figure 4.32: Mean hinge length and standard deviations (± 1σ) for two of the five layers of column sample D2 that is dated to the TRB from Bjørnsholm, plotted from lower down in the midden sequence, seven, to higher up, three. The size of each sample group was 10 shells.

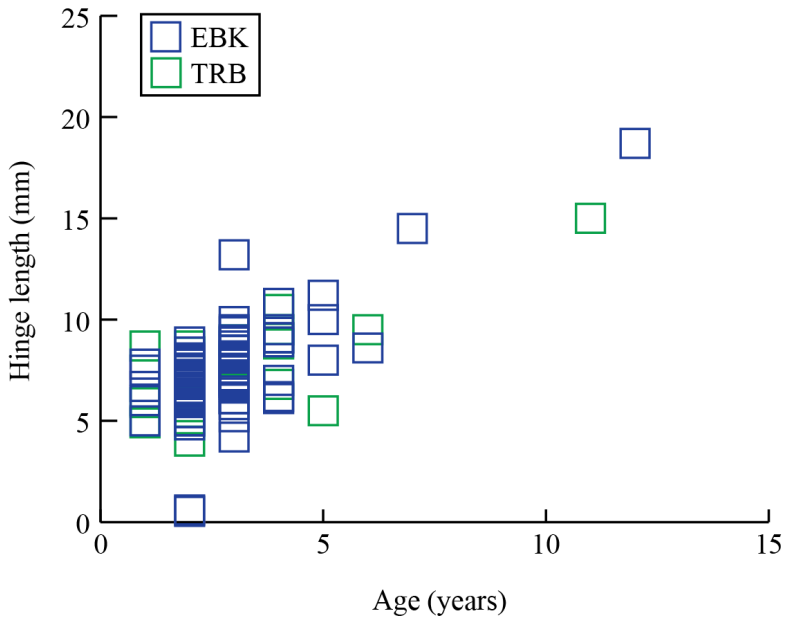


Figure 4.33: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from Bjørnsholm (n = 123).

Moving to Zealand the oysters dated to the EBK were similarly larger (10.0 ± 4.2 mm, *n* = 102) in the lower layers compared to the one TRB layer (6.9 ± 1.3 mm, *n* = 19) at the Eskilsø kitchen midden. Figure 4.34 presents the mean oyster hinge length per sample according to placement within the midden sequence. Overall the oysters derived from the EBK layers had similar hinge lengths. They were largest (12.5 ± 3.8 mm, *n* = 20) in layer two (sample F). An abrupt reduction in size appeared to have taken place between samples F to C and B, which is probably the result of an environmentally derived changed during the EBK that continued into the TRB. Despite the apparent diminution in size only one sample derived from the TRB that could have skewed the results.

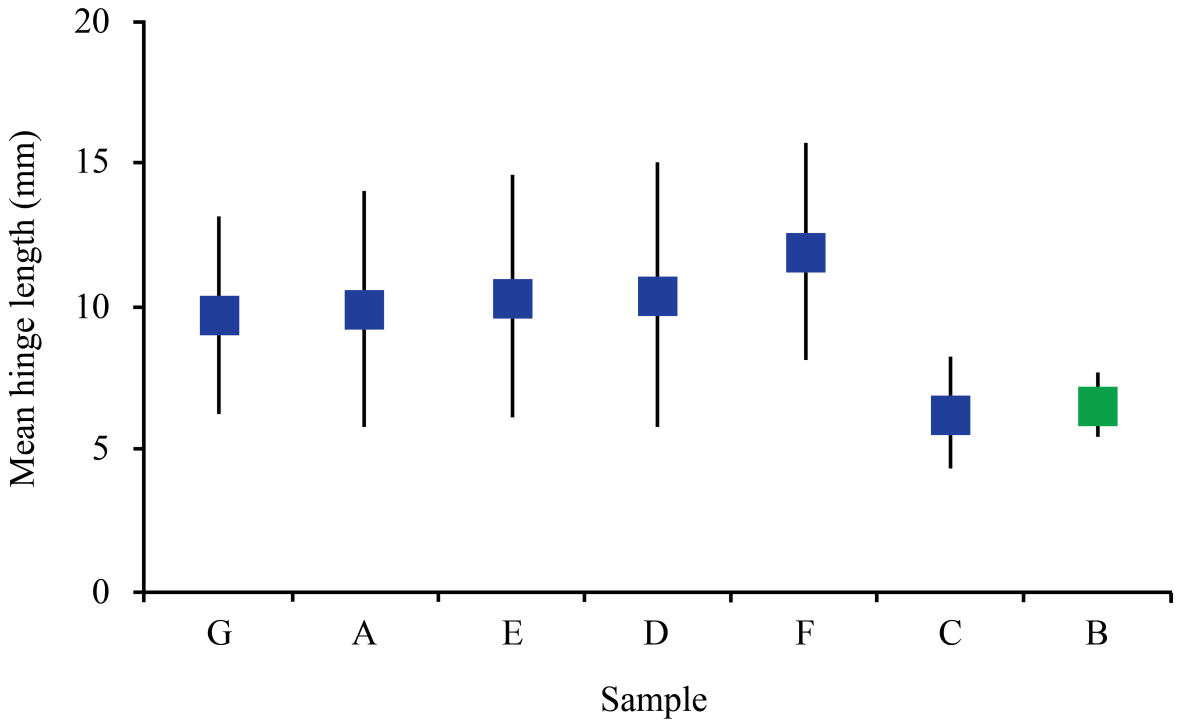


Figure 4.34: Mean hinge length and standard deviations (± 1σ) for the oysters from Eskilsø, plotted from lower down in the midden sequence, G, to higher up, B. The size of each sample group was >10 shells: G, n = 12, A, n = 19, E, n = 16, D, n = 13, F, n = 16, C, n = 18, B, n = 17.

Comparison between age and oyster shell length demonstrated a positive correlation (Figure 4.35). The EBK shells (samples A, C, D, E, F and G) are both larger and older than the TRB oysters from sample B. Overall the oysters in the EBK were older (7.9 ± 5.8 years, *n* = 93) than those from the TRB (3.4 ± 1.4 years, *n* = 16). The decrease in the age structure

of the natural population was probably related to increased exploitation. This pattern is atypical and was observed at the Havnø, Krabbesholm II (Figure 4.36) and Norsminde kitchen middens on Jutland (Milner 2013; Milner and Laurie 2009). However, a diminution in size related to environmental factors or disease cannot be ruled out. Given the small number of samples deriving from the TRB, a difference in size could conceivably be consistent with increased exploitation with younger oysters being harvested over time.

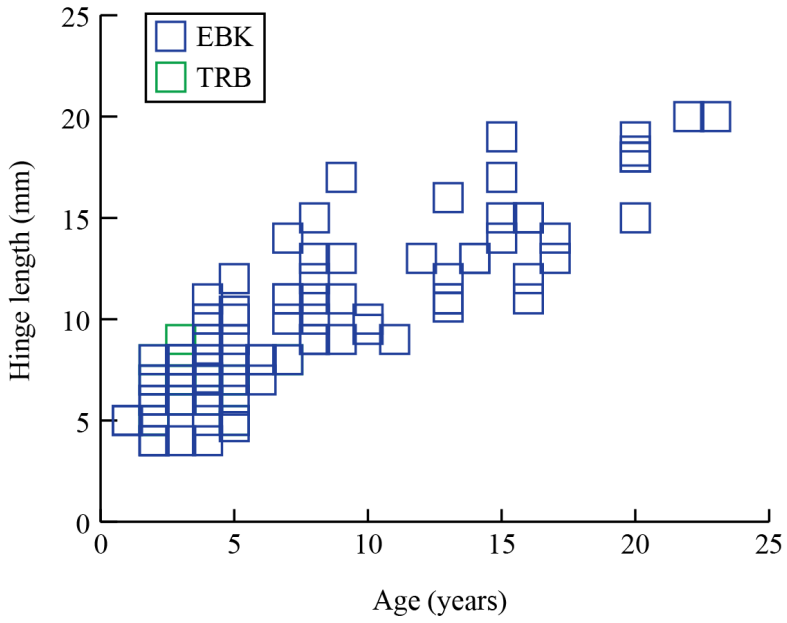


Figure 4.35: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from Eskilsø (n = 104).

A positive correlation between age and oyster shell length was similarly identified at the Krabbesholm II kitchen midden (Figure 4.37). Overall the oysters were marginally larger (8.9 ± 1.8 mm, n = 21) in the EBK than the TRB (7.6 ± 2.3 mm, n = 234). Similarly they were older (4.8 ± 2.3 years, n = 18) in the Mesolithic than the Neolithic (3.8 ± 1.6 years, n = 166). Amalgamation of both datasets (Milner 2001a; Milner and Laurie 2006) produced different data than the original interpretations that is probably a result of the larger sample size (i.e. smaller and younger oysters from higher up in the midden sequence). It would appear that human exploitation is having a demonstrable affect on the natural shell beds.

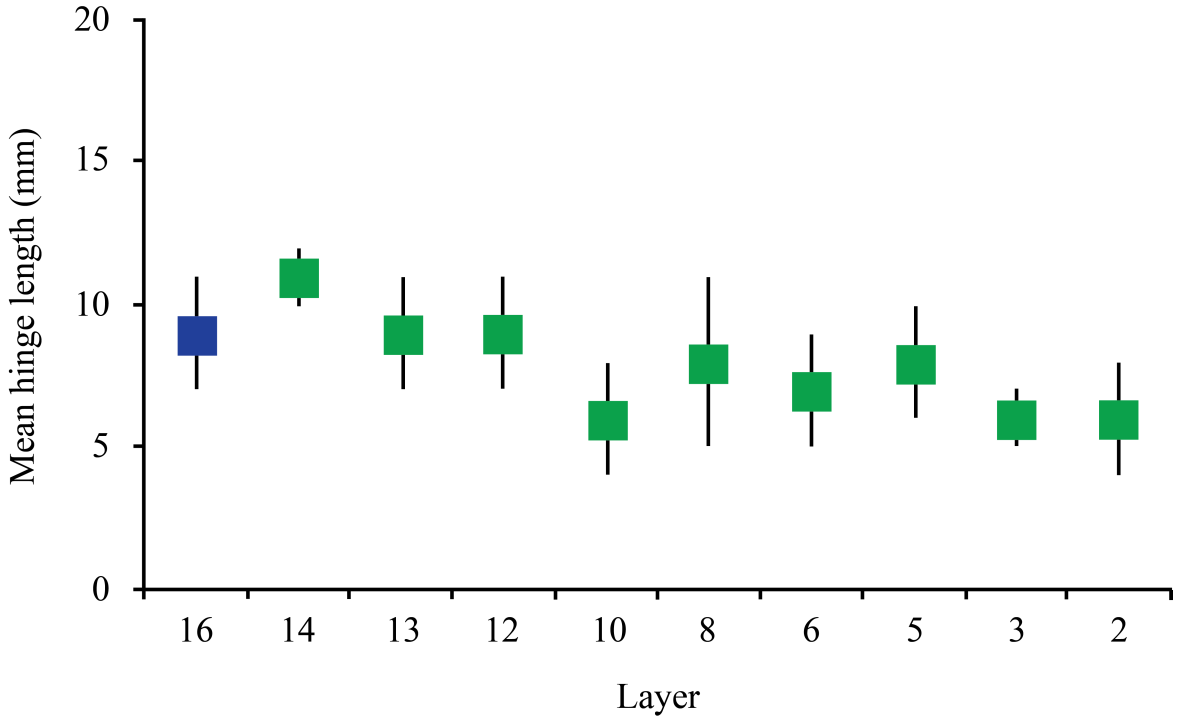


Figure 4.36: Mean hinge length and standard deviations (± 1σ) for the oysters from Krabbesholm II, plotted from the bottom of the midden sequence, 16, to the top, 2. The size of each sample group was >10 shells: 16, n = 21, 14, n = 10, 13, n = 13, 12, n = 54, 10, n = 29, 8, n = 15, 6, n = 16, 5, n = 32, 3, n = 16, 2, n = 33 (after Milner 2001a, 2013; Milner and Laurie 2006).

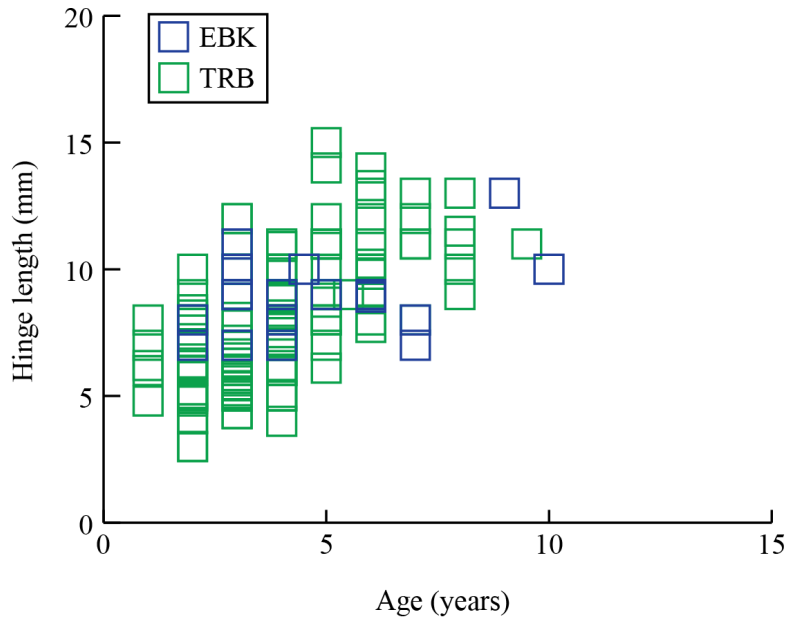


Figure 4.37: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from the Krabbesholm II kitchen midden (n = 182).

Figure 4.38 presents the mean oyster hinge length per layer of column sample N77 from the

Norsminde kitchen midden. In a similar manner to both Eskilsø and Krabbesholm II there was a diminution in size temporally throughout the midden sequence. Thus, the oysters were largest in the lower layers of the EBK midden than the higher layers of the TRB midden. The mean hinge length for the shells in layers seven to 10 was 7.7 ± 1.6 mm (n = 61), whereas those in layers one to six were 6.1 ± 1.5 mm (n = 60). In addition there was a change in the composition of the layers. Notably oysters and cockles dominated the EBK layers whereas cockles were the predominant species in the TRB layers (Andersen 1989; Milner 2002a, 2013; Milner and Laurie 2009).

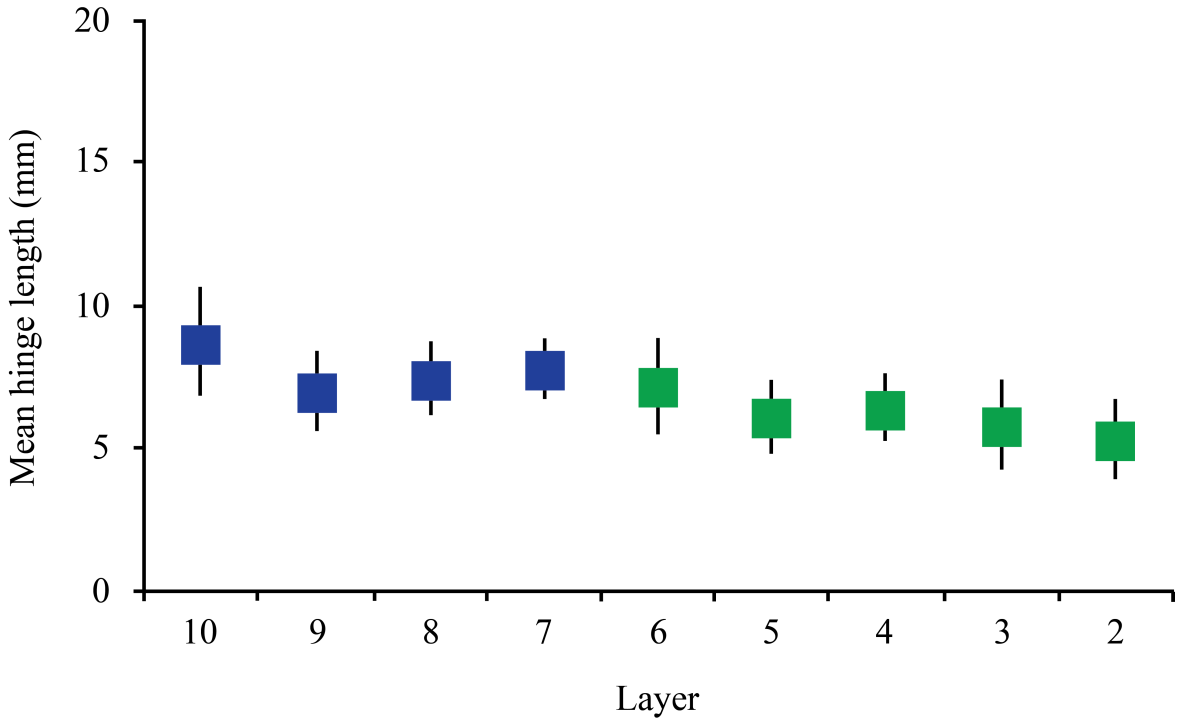


Figure 4.38: Mean hinge length and standard deviations (± 1σ) for the oysters from Norsminde, plotted from the bottom of the midden sequence, 10, to the top, 2. The size of each sample group was >10 shells: 10, n = 15, 9, n = 18, 8, n = 18, 7, n = 10, 6, n = 10, 5, n = 11, 4, n = 10, 3, n = 10, 2, n = 10 (after Milner 2002a, 2013; Milner and Laurie 2009).

Similarly there was a reduction in the age of the shells over the course of material deposition. On average the oysters from the EBK were older (3.4 ± 1.2 years, n = 54) than those from the TRB (2.5 ± 1.0 years, n = 46). However, the oysters in layer six had an identical size to the shells from layer 10 (3.9 years). This can be partly explained by either a

hiatus or a reduced period of exploitation.

Age and oyster shell length had a positive correlation (Figure 4.39). It can be seen that the EBK oysters were slightly larger for their age when compared to the TRB shells. In addition there are also more oysters older than four years in the EBK (Milner 2002a). In sum, since the age structure of the natural oyster population decreased over time this was probably the result of the intensity of harvesting during the TRB (Milner 2002a, 2013; Milner and Laurie 2009).

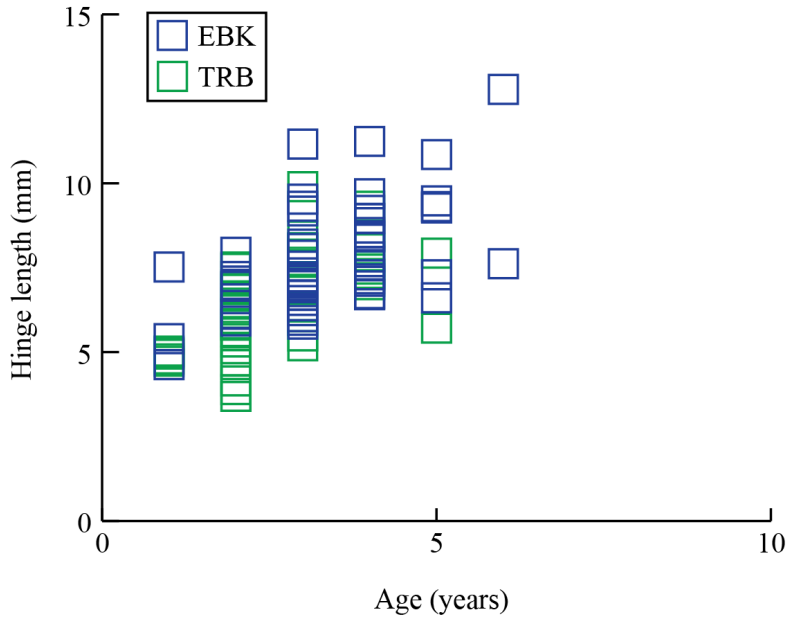


Figure 4.39: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from the Norsminde kitchen midden (n = 100).

4.7.3.4. The Visborg kitchen midden

As has been previously stated the oysters from Visborg were visually larger and older, and comparison between the two studies has indicated that this is not on account of the sampling strategies employed: essentially the data are identical. In the first study (Milner 2002a) the oysters had a mean hinge length of 8.6 ± 2.8 mm (n = 47), and were 3.9 ± 1.7 years old (n = 42), whereas in the present study the shells had a mean hinge length of 8.7 ± 1.8 mm (n = 245), and were 4.2 ± 1.9 years old (n = 145). When amalgamated the oysters had a mean hinge length of 8.7 ± 2.0 mm (n = 292), and were 4.1 ± 1.8 years old (n = 187). Despite the spatially dependent sampling strategy the oysters had a uniquely uniform hinge

length (Figure 4.40). When grouped together it can be seen that age and oyster shell size had a positive correlation (Figure 4.41).

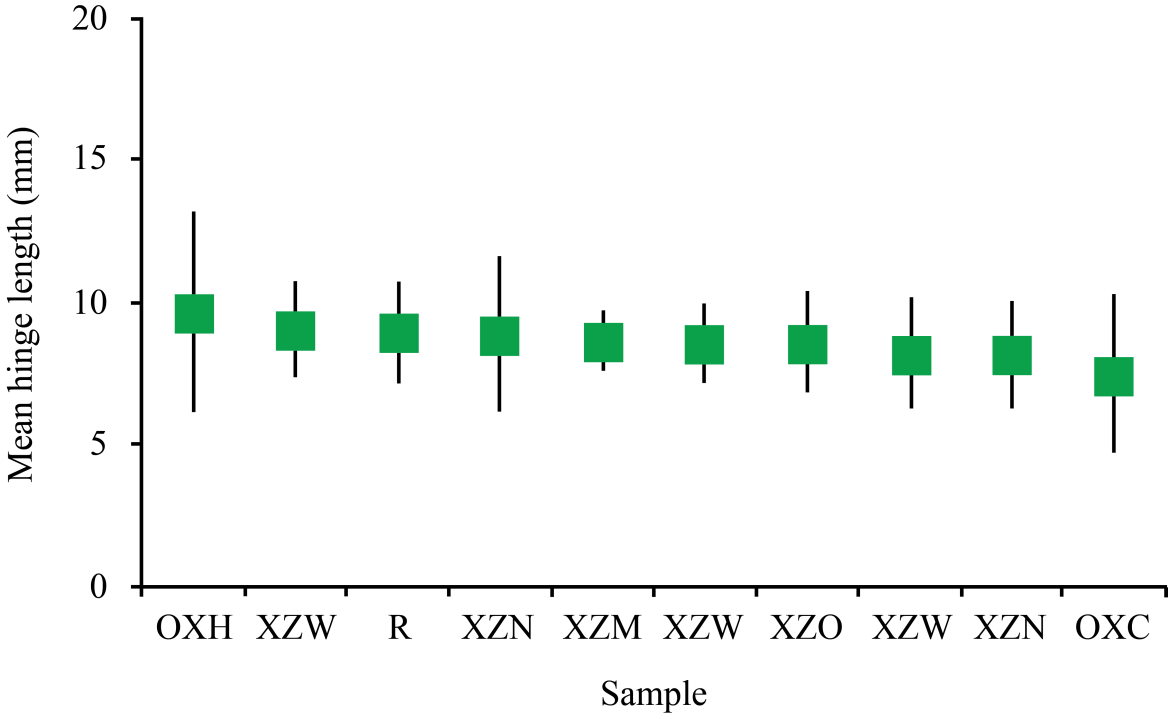


Figure 4.40: Mean hinge length and standard deviations (± 1σ) for the oysters from Visborg, plotted in descending order. The size of each sample group was >10 shells: OXH, n = 10, XZW, n = 19, R, n = 10, XZN, n = 20, XZM, n = 24, XZW, n = 21, XZO, n = 10, XZW, n = 19, XZN, n = 20, OXC, n = 10.

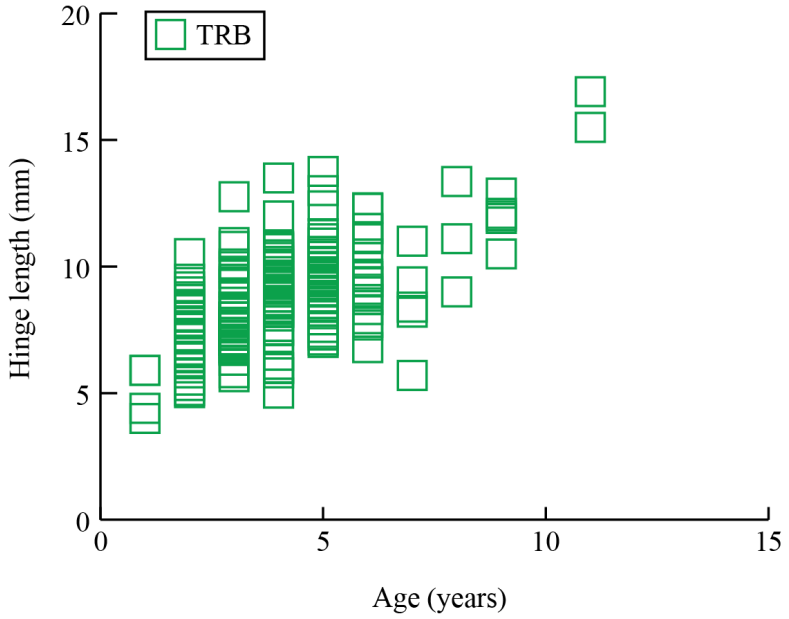


Figure 4.41: Scattergraph plotting the ages (years) against hinge lengths (mm) obtained from oyster shell samples from the Visborg kitchen midden (n = 185).

Additional work is required to securely identify exactly where the samples were taken within the kitchen midden, however, when the samples are amalgamated according to section, spatial differences can be explored (Table 4.5).

Section	Samples	Hinge length (mm)		Age (years)	
		Sample size	Mean ± STDV	Sample size	Mean ± STDV
1	1, 2, 6 & 7	86	8.7 ± 1.9	63	4.1 ± 1.9
2	8-10	58	8.6 ± 1.7	34	4.4 ± 1.7
3 & 3a	11-13	34	9.0 ± 1.3	19	4.9 ± 0.8
4 & 4a	3, 4, 14-19	71	8.5 ± 2.4	45	3.7 ± 2.0
5	20, 21, 21a, 22, 23a & 23b	33	8.7 ± 2.1	16	4.1 ± 2.3

Table 4.5: Summary statistics (± 1σ) for the various samples from Visborg.

The oysters were largest in sections three, and three 'a'. The shells from section one followed and it was possible to examine temporal change (Figure 4.42). There was a slight reduction in oyster hinge size between samples seven (9.3 ± 1.9 mm, n = 34), and six (8.5 ± 1.2 mm, n = 33). Interestingly the shells from section five were essentially identical to section one, excluding the standard deviations. Sections one and five were followed by section two. The smallest shells are derived from section four.

Overall the variation in the oyster hinge size across the kitchen midden was 0.5 mm. Likewise the oysters were oldest in sections three and three 'a'. They were slightly younger in section two. Sections one and five were essentially identical besides the difference in the standard deviations. Likewise the oysters in section four were the smallest.

Interestingly the oysters had an almost identical mean hinge length to the TRB shells from the Havnø kitchen midden. Overall, they were larger than the shells from both the Ertebølle and Bjørnsholm kitchen middens regardless of period of culture. In addition, they were larger than the TRB shells from the Eskilsø, Krabbesholm II and Norsminde kitchen middens.

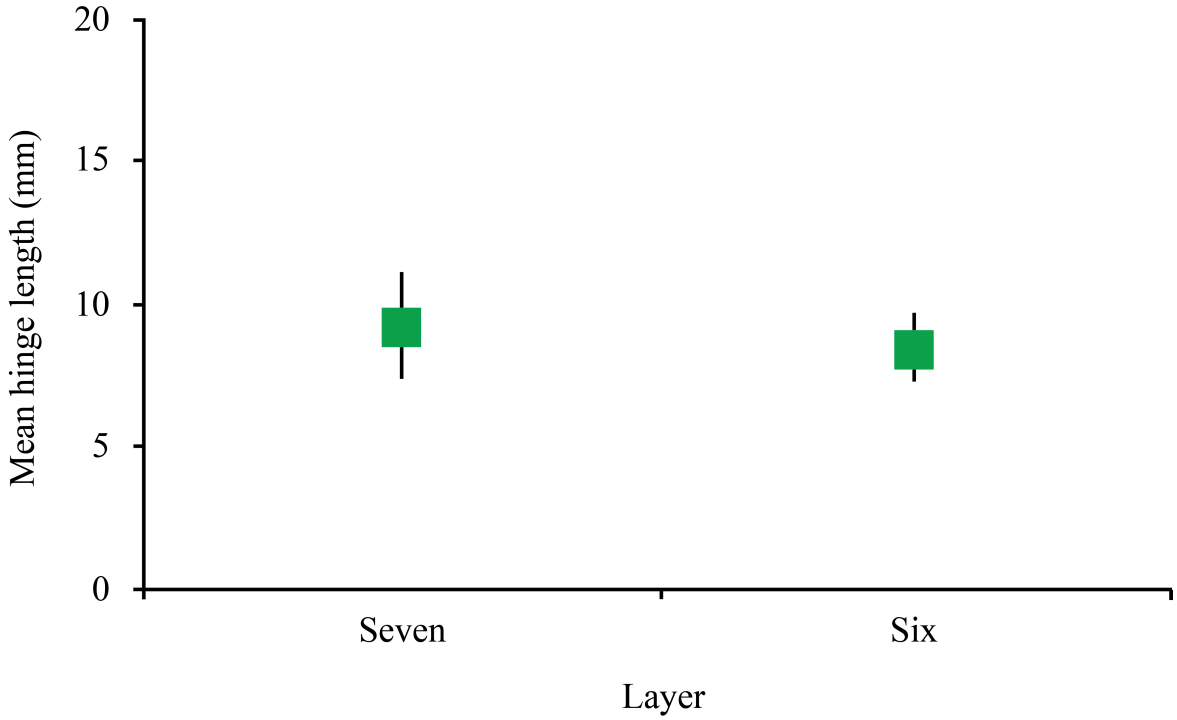


Figure 4.42: Mean hinge length and standard deviations (± 1σ) for the oysters from section one at Visborg, plotted in descending order. The size of each sample group was >10 shells: Seven, n = 34, Six, n = 33.

4.7.3.5. Regional variation

The summary statistics for the hinge lengths (mm) and ages (years) obtained on EBK, TRB and SGC oysters per sampled site are shown in Table 4.6. The mean oyster hinge lengths and ages for the EBK samples are plotted according to sample location in Figures 4.43 and 4.44, whereas Figures 4.45 and 4.46 plots the TRB and SGC data. In general the oysters were larger and older in the EBK compared with the TRB and SGC. However, regional variation was apparent. During the EBK the shells from Havnø were the largest (11.4 ± 3.6 mm), whereas the oysters from Ertebølle were significantly smaller (5.2 ± 2.1 mm). The shells from Eskilsø followed Havnø that no doubt reflect an unexploited natural population at the time of material deposition (10.0 ± 4.2 mm). Despite the few readable thin sections from the Lystrup Enge kitchen midden, the oysters had a mean hinge length of 9.2 ± 3.2 mm. Excluding these, the shells from the Norsminde Fjord as well as the numerous other sites sampled along the eastern Jutland coastline had mean lengths ranging from 5.7 ± 1.3 mm (Dyngby III) to 7.9 ± 2.2 mm (Eskelund). The shells from the submerged settlement at Tybrind Vig were marginally larger (5.3 ± 2.3 mm) than those from Ertebølle. The

Limfjord exhibited considerable variation. The oysters from the southernmost sampled site, Krabbesholm II, were the largest (8.9 ± 1.8 mm), whereas those from Bjørnsholm and Brovst were almost identical (7.9 ± 6.0 mm and 7.4 ± 2.8 mm respectively). Ertebølle is situated just south of Bjørnsholm and these shells were the smallest out of all of the sites sampled that may be a reflection of an influx of more saline waters from the North Sea.

Site	Culture	Mean hinge size (mm)	Mean age (years)
Bjørnsholm	EBK	7.9 ± 6.0	2.7 ± 1.4
	TRB	7.2 ± 2.1	3.1 ± 2.1
Brovst	EBK	7.4 ± 2.8	2.9 ± 1.4
Dyngby I	EBK	6.0 ± 1.5	2.2 ± 0.8
Dyngby III	EBK	5.7 ± 1.3	2.4 ± 1.0
Ertebølle	EBK	5.2 ± 2.1	2.4 ± 1.1
Eskelund	EBK	7.9 ± 2.2	2.8 ± 0.8
Eskilsø	EBK	10.0 ± 4.2	7.9 ± 5.8
	TRB	6.9 ± 1.3	3.4 ± 1.4
Havnø	EBK	11.4 ± 3.6	6.5 ± 3.6
	TRB	8.6 ± 1.8	3.7 ± 1.8
Holmegård	EBK	6.2 ± 1.4	1.9 ± 1.0
Kalvø	SGC	9.3 ± 2.2	3.4 ± 1.0
Krabbesholm II	EBK	8.9 ± 1.8	4.8 ± 2.3
	TRB	7.6 ± 2.3	3.8 ± 1.6
Lystrup Enge	K/EBK	9.2 ± 3.2	3.3 ± 1.5
Norsminde	EBK	7.7 ± 1.6	3.4 ± 1.2
	TRB	6.1 ± 1.5	2.5 ± 1.0
Tybrind Vig	EBK	5.3 ± 2.3	3.7 ± 2.1
Vængesø III	EBK	7.9 ± 1.4	3.4 ± 0.7
Visborg	TRB	8.7 ± 2.0	4.1 ± 1.8

Table 4.6: Summary statistics (± 1σ) for the 16 sampled sites according to cultural epoch (after Milner 2001a, 2002a; 2013; Milner and Laurie 2006, 2009).

The mean age was ascertained by counting the annual lines except for the first year of growth (also termed the juvenile line) (Milner 2001b). These data are almost identical to the aforementioned hinge length data. However, the oysters from Eskilsø were the oldest (7.9 ± 5.8 years), while Havnø followed (6.5 ± 3.6 years). Similarly variation was observed

along the eastern coastline of Jutland with values ranging from 1.9 ± 1.0 years (Holmegård) to 3.4 ± 1.2 years (Norsminde). Likewise there was variation throughout the Limfjord. The oysters were oldest from Krabbesholm II (4.8 ± 2.3 years) and those from Ertebølle were the youngest (2.4 ± 1.1 years).

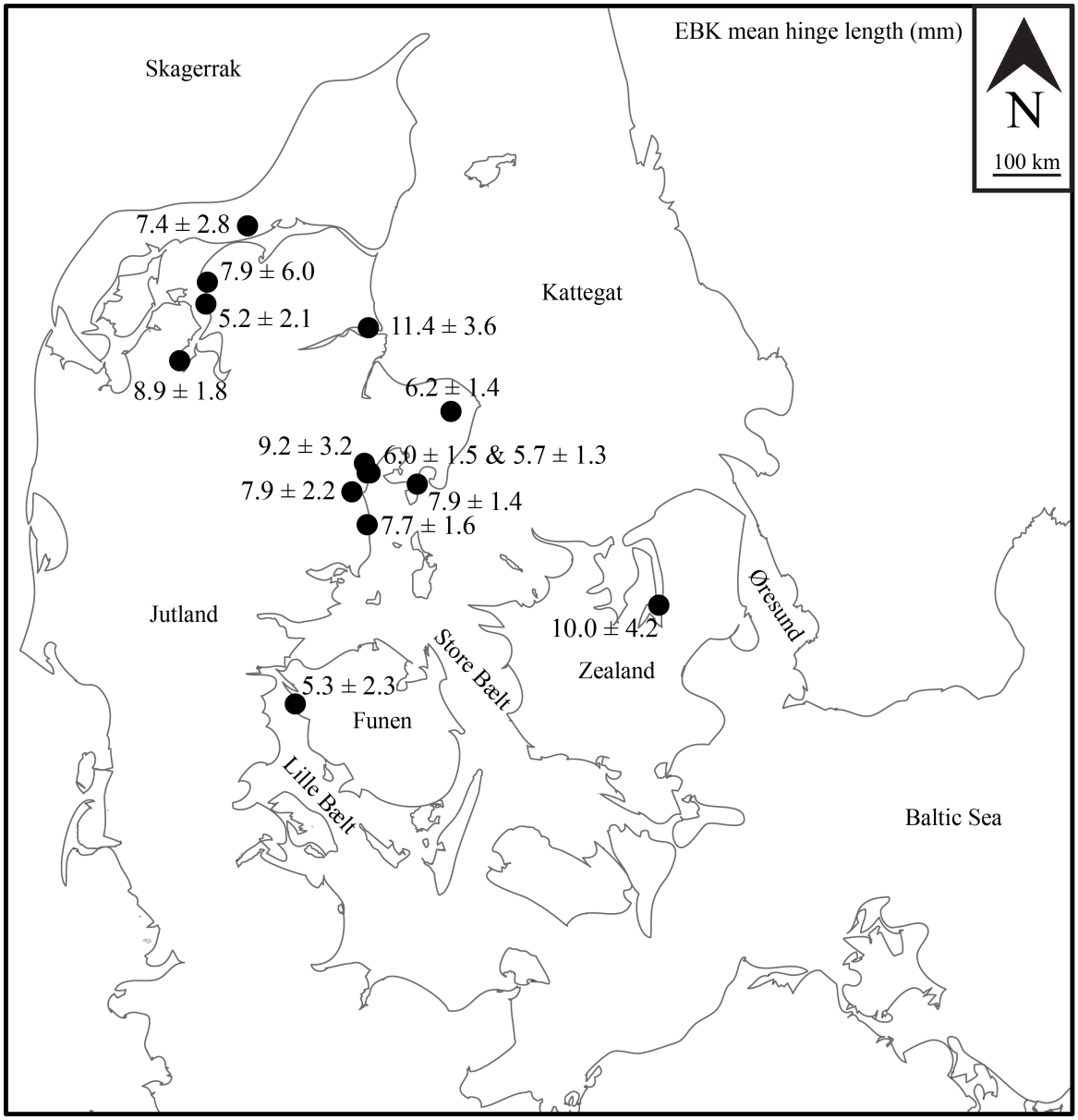


Figure 4.43: Mean hinge length and STDVs (± 1σ) per EBK site.

As has been previously mentioned the oysters dating to the TRB were on average smaller than those dating to the EBK. Despite oscillations throughout column samples (e.g.

Krabbesholm II), at every stratified kitchen midden the oysters are smaller in the TRB: Bjørnsholm, Eskilsø, Krabbesholm II, Havnø and Norsminde. Despite the fact that the very large sample from Visborg was composed of only TRB oysters, they are comparable with Havnø. Indeed they are almost identical and as such confirm that a likely diminution in size occurred throughout the Mariager Fjord. Perhaps the reduction in size is attributable to the outflow of water, intermixed with increased sediment runoff perhaps from agricultural activities and tree felling (Laurie 2008). Indeed additional samples from contemporaneous kitchen middens in the fjord could help to elucidate such assumptions. On the contrary the shells from Kalvø were considerably larger than those from Norsminde. Either this is a reflection of the much reduced sample size that has skewed the results or maybe it represented a terminus in oyster harvesting in the fjord between the TRB and SGC.

The inter-site variation in the size of the oyster hinge and shell is likely to be a product of the ambient microenvironments along the Danish coastline (Milner 2002a). Those oysters from the Mariager Fjord appeared to grow larger than those from the Limfjord, which is in part probably due to more favourable conditions. It is clear throughout prehistory that the different areas of Denmark sampled here were subjected to oscillations in the primary production, whereas the inter-site variation of the shell age is probably a reflection of both environmental factors as well as human overexploitation. Finer resolution sampling in the future may permit a detailed understanding of transgressions whereby the growth rate is significantly affected.

4.7.4. Comments on the methodology

4.7.4.1. Interpretation

In the initial study the seasonality interpretations had a margin of error of ± 1 month (Milner 2002a). Given the flexibility of the data seasonal assessments were made in the present study. Seasonal assessments are likely to be more representative since it takes into account possible environmental oscillations, and growth patterns since the Atlantic chronozone. Consequently when the previously published data (Milner 2001a, 2002a, 2013; Milner and Laurie 2006, 2009) were re-analysed they were comparable with the present

study since all readings are accurate to within a season. During the re-analysis it was identified that there were differences in how the oyster hinge measurements had been reported (i.e. cm or mm). Therefore it was deemed necessary to revisit and standardise all data to mm.

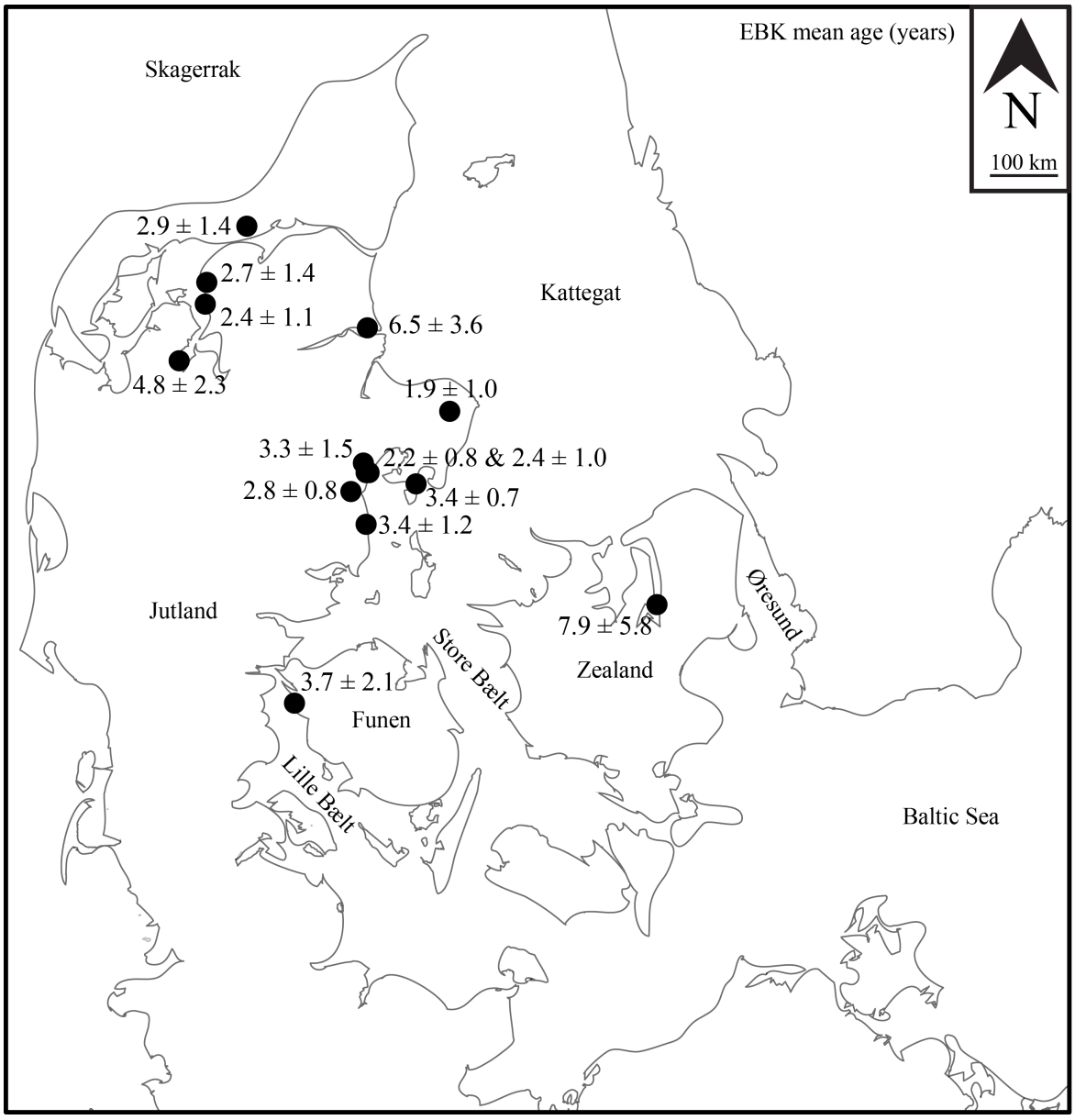


Figure 4.44: Mean age and STDVs (± 1σ) per EBK site.

4.7.4.2. Blind testing

In order to be sure the interpretations could be replicated, a blind test was undertaken by

either Eva Laurie or Nicky Milner for the samples deriving from Bjørnsholm, Brovst, Dyngby III, Ertebølle, Eskilsø, Havnø, Holmegård, Kalvø, Tybrind Vig, Vængesø III and Visborg. Since the two analysts had previously undertaken incremental growth line analysis, the readings are comparable with the previously published data but are also consistent. Where disagreement occurred all parties reviewed the thin sections, and after discussion a final agreement was reached on all readable shells, which were included in the final analysis.

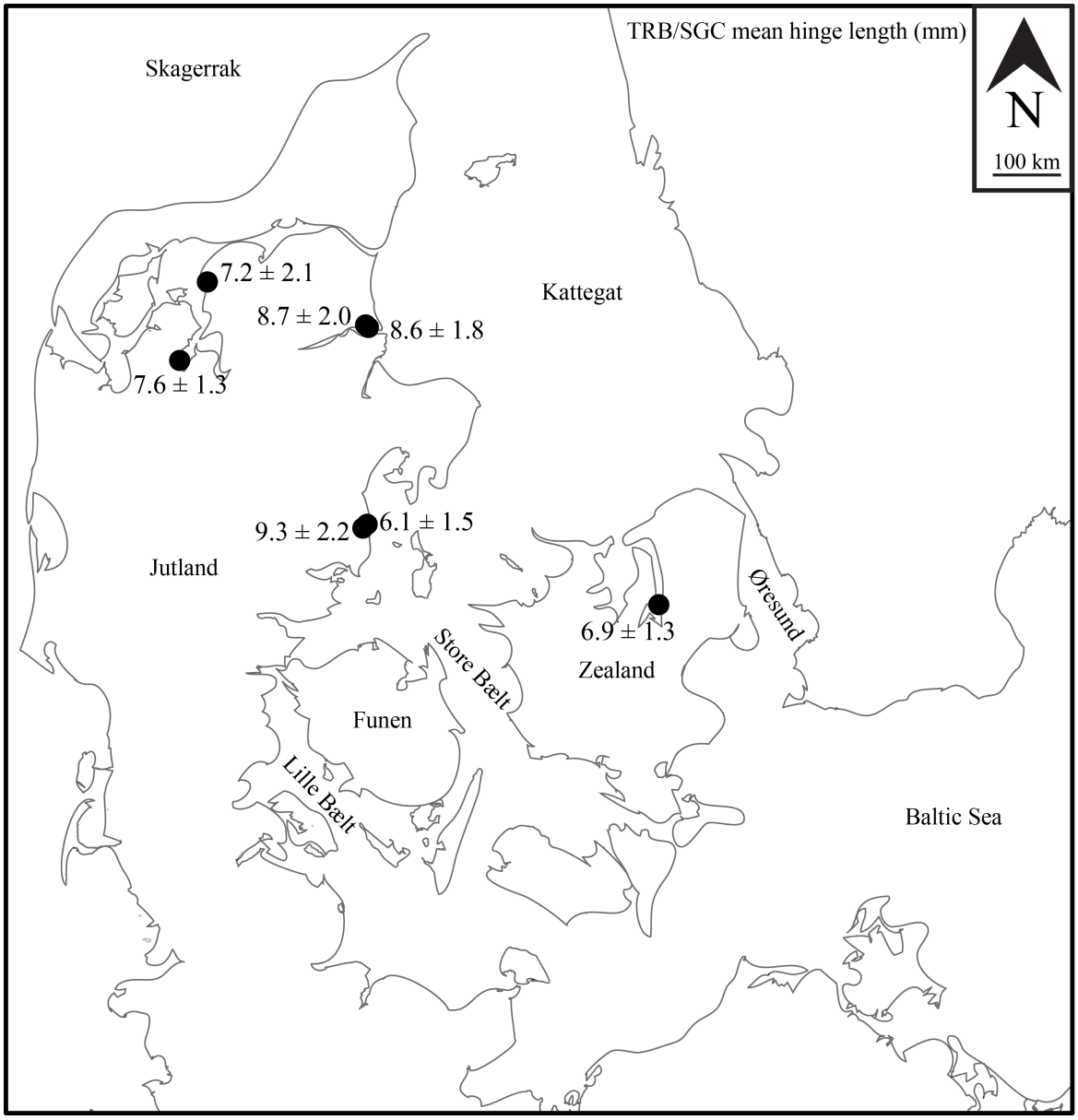


Figure 4.45: Mean hinge length and STDVs (± 1σ) per TRB/SGC site.

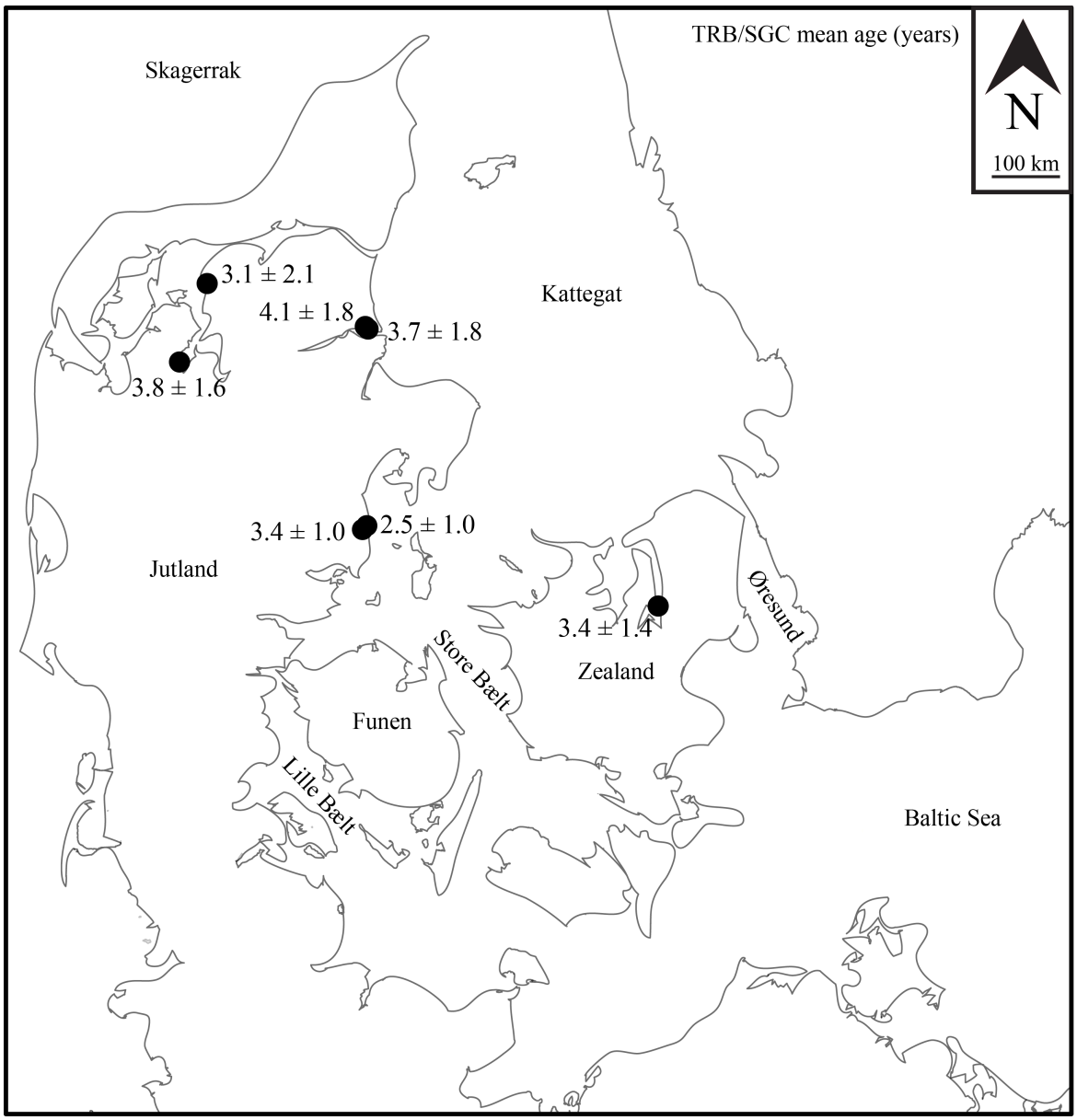


Figure 4.46: Mean age and STDVs (± 1σ) per TRB/SGC site.

4.7.4.3. Sampling strategy

This study stresses an important methodological point: that sample sizes need to be large, taken from numerous points, and where possible stratified in order to maximise the results. The initial pilot study from Havnø (Milner 2002a) had value in that it demonstrated that additional oysters from the kitchen midden were worth analysing. However, the small sample size of 17 shells, of which 13 yielded results (76.5%), produced different seasonality data to the one presented when a larger sample size was used. Since numerous

sampling points were excavated it has been possible to assess spatial and temporal variation at Havnø.

4.7.4.4. Previous analyses

The sampling strategies for the previous studies were largely based on: (1) availability of samples, (2) assessing change over time, (3) location within the site, and (4) how many thin sections could be made (Milner 2001a, 2002a, 2013; Milner and Laurie 2006, 2009).

While the availability of material was largely dependant on whether the site was being excavated at the time of research, of the 16 sites 10 samples were randomly selected. Since there is no way of knowing as to their location within the site, they are without a doubt unrepresentative (Milner 2002a). Indeed their inclusion is questioned as well as whether any meaningful interpretations can be made (Milner 2002a). Since only four thin sections could be read for seasonality from both Dyngby I and Lystrup Enge respectively their usefulness is questionable. However the remaining eight randomly selected samples yielded >10 readable thin sections, and it is argued that they have proven useful for providing an indication as to some of the seasons in which harvesting had taken place. Provided that humans exploited the oysters, when the data are grouped together with other seasonality information derived from other lines of enquiry, a more holistic interpretation for the site can be made (Milner 2002a). Furthermore when the AMS radiocarbon dates are taken into consideration it is possible to compare data on a regional scale during the EBK, TRB and SGC of Denmark.

In the study by Milner (2002a) one column sample deriving from Norsminde was analysed, and subsequent studies have emphasised their importance for assessing diachronic variation throughout a midden sequence (Laurie 2008; Milner 2013; Milner and Laurie 2006, 2009). In the present study numerous layers from column samples extracted from Bjørnsholm and Ertebølle were sampled. Despite the varying sample sizes per layer that are often <10, when the data are grouped together according to culture, the sample sizes are significantly increased (Milner 2002a).

For the majority of the sites sampled, oysters were taken from numerous sampling points, and this method has proven equally as important. In light of the above, subtle spatial and temporal differences were identified at Dyngby I and III, Havnø and Visborg. For instance, since a very thin shell layer was observed at Dyngby III and Visborg individual collection events have been identified that appear to have differed across the sites. Undoubtedly these small-time sequences are likely to have been obscured at sites with thicker midden sequences.

In the initial study the loss of thin sections during the manufacturing process or during the microscopic analysis was not anticipated (Milner 2002a). As such approximately 20-25% of the samples selected for analysis were discarded. In the present study discard rates varied from 21.3% (Kalvø) to 60.7% (Dyngby III) and are probably attributable to a number of factors: accumulation and animal agents, natural elements and natural agents, as well as the affects by archaeologists and analysts during recovery and analysis (Marean *et al*. 2004). In light of the above and the recommendations by Milner (2002a), except for Brovst a sample size in the region of 20 oysters was achieved per site (Table 4.7). However, in cases when <10 shells were selected for analysis, once the data are grouped together the interpretation is greatly improved.

Site	**Selected samples**	**Success rate (%)**	**Discard rate (%)**
Bjørnsholm	232	56.5	43.5
Brovst	18	50.0	50.0
Dyngby I	33	63.6	36.4
Dyngby III	56	39.3	60.7
Ertebølle	156	51.3	48.7
Eskelund	20	75.0	25.0
Eskilsø	130	78.5	21.5
Havnø	154	59.7	40.3
Holmegård	32	53.1	46.9
Kalvø	33	78.7	21.3
Krabbesholm II	206	92.9	7.1
Lystrup Enge	13	30.8	69.2
Norsminde	121	79.3	20.7
Tybrind Vig	20	63.2	36.8
Vængesø III	21	61.9	38.1
Visborg	295	62.7	37.3

Table 4.7: Successful and unsuccessful data for the 16 sites sampled.

4.7.4.5. Recommendations

Seasonality analysis can often be time consuming, and many methods are expensive which is why sample sizes are often small. However, sample size and potential bias during the interpretation of results should always be borne in mind when examining the data. It is essential to have a clear contextual control during sampling, and the application of AMS radiocarbon dating has proven a useful asset for determining the relative age of the samples. When assessing temporal variation column sampling is advisable, however in cases that do not permit such extraction, the sample should be large enough and take into account multiple collection events. Similarly for intra-site variation, numerous points or layers should be sampled as was carried out at Dyngby I, Dyngby III, Havnø and Visborg. Despite large datasets, often-individual samples are very small, for instance the layers from Ertebølle, and numerous samples from Visborg, therefore it is necessary to group samples together to aid in our interpretation.

4.8. Conclusions

In the case of Havnø there was a continuation of marine mollusc exploitation, in that oysters were being consumed in large numbers throughout the lifespan of the kitchen midden formation, and yet there were changes, including a shift in the season of death, a change in the frequency of the species being gathered, albeit cursory at present, and changes in oyster shell hinge length and age. However, it is perhaps worth reiterating that not all of these changes occurred simultaneously, or indeed are coincident with the change in material culture at the Mesolithic-Neolithic within the kitchen midden (Milner and Laurie 2009). During the EBK harvesting appeared to be focussed in the spring and autumn. The seasonality signature did not change substantially in the TRB layers of the kitchen midden with the exception of the small peak during the summer for the EBK. It is very difficult to know how representative this picture is because we are dealing with small sample sizes and time-averaged layers (Milner and Laurie 2009). One thing is for certain is that seasonal gathering does not appear to be consistent through time, and this highlights the benefits of sampling from multiple points across the kitchen midden, as well as the use of column sampling for ascertaining diachronic variation as has been employed at a number of Danish kitchen middens including, Krabbesholm II (Laurie 2008; Milner and Laurie

2006), Norsminde (Milner 2002a; Milner and Laurie 2009), and now Bjørnsholm and Ertebølle. It is equally as difficult to interpret the cause of these changes, because seasonal collection events may be related to multiple inextricable practices, including economic, environmental, social and ritual (Milner 2005).

From an inter-site perspective, the EBK data from Havnø are notably different to those observed elsewhere, thus highlighting the importance for examining different sites in detail, and for not assuming a seasonal strategy for oyster harvesting for the EBK as a whole. It can be seen that oyster consumption continued into the TRB in the Mariager Fjord, but that a change occurred with gathering being undertaken throughout much of the year at Visborg.

The size and age measurements demonstrated similar patterns of exploitation for the stratified kitchen middens (Bjørnsholm, Eskilsø, Havnø, Krabbesholm II and Norsminde). In general, it appeared that oysters became smaller in size and younger with age. In part, the inter-site variation in the size of the shell hinge and age maybe the product of the local microenvironment around the Danish coastline (Milner 2002a). Equally it also suggests that there continued to be intensive gathering with the scale of human consumption being so great enough to have had a significant impact on the natural oyster population. On the other hand, Rowley-Conwy (1984) has argued that whilst the seasonal usage of oysters, in the region of two to three months, was essential in plugging the gap in the EBK resource cycle, the decline in marine salinity was the causal factor for the oyster decline which may in turn have triggered the adoption of farming in Denmark. Although there is some evidence that salinity reduced (Nielsen 1938; Nordmann 1903), at present it is not clear whether this would have affected the oysters so drastically. Certainly this effect would have varied regionally, although in some areas of Jutland oysters persisted well into the Neolithic (e.g. Kalvø).

Additional work is required in order to ascertain how these data relate to the elusive and fragmentary economic and settlement evidence over this time period (Blankholm 2008; Milner and Laurie 2009; Rowley-Conwy 2014). For instance, can these seasonal interpretations fit into the practices of changing settlement patterns in the early Neolithic,

including the movement of people between the coast and hinterland (although see Fischer *et al*. 2007 for contrary evidence which suggests that coast-inland mobility must have been a regular phenomenon in the Mesolithic of Denmark), and the introduction of agriculture and domestication, albeit on probably a small scale at the onset? The fact however that oysters continue to be intensively exploited throughout the year in the TRB layers for a number of the sampled sites certainly suggests that marine molluscs are still a much sought-after resource. In order to investigate these questions, the seasonality of shellfish procurement needs to be related to other investigations of seasonal resource exploitation, for instance oxygen isotope analysis of fish otoliths, and at similar scales of analysis. Unfortunately this is seldom carried out, and palimpsests such as these are often reduced to represent the typical year-round resource cycle for the EBK (Milner 2005; Milner and Laurie 2009).

Additionally, it is important to consider inter-site variation when investigating the Mesolithic-Neolithic transition, and to attempt different scales of analysis. If stratified kitchen midden material with clear stratigraphy and long life spans is examined at a finer resolution, it can be seen that in fact whilst the accumulation, and formation processes is more complex, it maybe possible to ascertain a more subtle understanding of the continuity and change in the economy and food consumption practices across the Mesolithic-Neolithic transition.

In conclusion, this evidence does not easily tally with the interpretation of early Neolithic people who have successfully turned to agriculture, and no longer require marine resources for consumption. Whilst the kitchen midden is situated on what was once an island, clearly people were either living there at this time, or that the island was tidally accessible, not an island for the duration of the midden accumulation, or that they were visiting the island by dugout canoe or sledge, depending upon the time of the year, and continuing to harvest the natural resources (Gron 2013a; Milner and Laurie 2009; Milner *et al*. 2004). Since their practices did not change so drastically, this suggests that some other economic changes were perhaps taking place, such as experimention with new domesticated products.

5. Organic residue analysis of ceramic vessels

5.1. Introduction

This chapter commences with an overview of EBK and TRB ceramic vessels in southern Scandinavia. This will be followed by an outline of the methods and sampling procedures that have been developed for the organic residue analysis (hereafter ORA) of ceramic vessels in order to examine practices of consumption and cuisine. Organic residue analysis of the ceramic vessels from the Havnø kitchen midden will then be presented.

There were two main objectives:

- To identify whether molecular signals deriving from aquatic organisms survive (as demonstrated by Craig *et al*. 2007, 2011 from contemporaneous ceramic vessels in the region), and whether this was consistent across the EBK and into the TRB.
- To compare the use of the ceramic vessels at Havnø with other contemporaneous Danish coastal and inland material to assess regional variability.

For inter-site comparison, six additional archaeological sites dating from the EBK to the TRB cultures were sampled: the Åle, and Bjørnsholm kitchen middens, and the submerged isolated find spots and settlement sites at Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde, and Tybrind Vig. In addition, ORA that had been previously undertaken from 13 other sites by Oliver Craig and Carl Heron were analysed. Furthermore, published results from ORA for 10 sites have been examined (Craig *et al*. 2007, 2011; Fischer and Heinemeier 2003; Heron *et al*. 2013; Richter and Noe-Nygaard 2003). Thus, the Havnø data can be interpreted within the context of 24 Danish archaeological sites.

5.2. Ceramics of the Danish EBK and TRB

5.2.1. History of research

Since the beginning of Ertebølle research ceramics have been recognized by some as a part of the culture's economy (Povlsen 2014; Worsaae 1862). The first description of the two

EBK vessel types was provided in 1888 (Müller 1888), and was developed further by *The Second Kitchen Midden Commission* (Madsen *et al*. 1900). In 1900 use-wear was identified, and a description of the vessels was provided, including the fabrication and coiling techniques. In addition, decorations on the rims were noted as well as drilled holes that were indicative of repairs. Their distribution within the Ertebølle kitchen midden was described and led to a number of partial refits (Andersen 2011a; Madsen *et al*. 1900).

Despite the prevalence of ceramic vessels within EBK assemblages it was not always recognized that the EBK had a pre-ceramic phase despite the sites at Henriksholm and Nivågård proving otherwise (Becker 1939). The pre-ceramic phase was subsequently confirmed by the excavations at the Norslund kitchen midden (Andersen and Malmros 1966), as well as the re-excavations of the eponymous Ertebølle kitchen midden (Andersen and Johansen 1986).

Similarly, debate ensued following the presumption that the EBK ceramics were contemporaneous with the TRB (Rydbeck 1928). While Mathiassen (1937) suggested that they belonged to the later Neolithic, this opinion was refuted two year later by Becker (1939) based, in part, on the excavations undertaken at Ordrup Næs. In a subsequent publication by Mathiassen (1943) it was demonstrated that the EBK ran in parallel with the TRB, which was based on his own observations from excavations undertaken on several kitchen middens (Mathiassen *et al*. 1942) and inland sites in the Store Åmose (Mathiassen 1943). Following these debates Becker (1954) reduced the time frame of the EBK to encompass the early and middle Neolithic, whereas Troels-Smith (1967) viewed the EBK ceramics as being a part of the early Neolithic, in particular Becker's A-group. It was not until the application of AMS radiocarbon dating that quelled the debate that had been ongoing for over 30 years. Analyses undertaken by Tauber (1966, 1971, 1973) demonstrated that the TRB succeeded the EBK and there was no overlap between the two (Andersen 1973).

5.2.2. Chronology

Originally lithics were used to date ceramic vessels (Kjellmark 1903; Thomsen and Jensen

1906), and then *vice versa* (Brinch Petersen 2011) through the AMS radiocarbon dating of adhering food crusts (Andersen 1981; Koch 1998). However, it has been recently demonstrated that these data are, to a degree, unreliable. This is based, in part, on a significant freshwater reservoir effect (FRE) originating from the recycling of old calcium carbonates that are dissolved with the ground water. Consequently, old radiocarbon ages of samples derived from aquatic localities have been obtained (Fischer and Heinemeier 2003). For example, the remains of humans who consumed freshwater fish, and ceramic vessels in which aquatic foodstuffs were processed (Fernandes *et al*. 2013; Philippsen 2013; Philippsen and Meadows 2014; Philippsen *et al*. 2010).

In the Store Åmose the AMS radiocarbon dating of contemporary fish remains have demonstrated an age in the region of 100-500 radiocarbon years, whereas the food crusts vary up to approximately 300 radiocarbon years (Fischer and Heinemeier 2003). Despite these inherent issues it is generally accepted that in Denmark the earliest ceramics appeared from ca. 4800-4600 cal BC at both coastal and inland localities (Andersen 2010, 2011a). This chronological range is based on the fact that the ceramics are younger than 4850 cal BC at the Norslund kitchen midden, while they are between 5000-4700 cal BC at the Brovst kitchen midden (Andersen 1970; Andersen and Malmros 1966).

Another issue stems from the fact that their emergence is based exclusively on the ceramics of western Denmark since there are a lack of dates from both Funen and Zealand. On Zealand there is only one site, Vejlebro, which has been dated to ca. 4400 cal BC. This is problematic given the previously published work on material from Zealand (Fischer 2002; Nielsen 1986; Troels-Smith 1953). It is therefore difficult to determine whether the first ceramics appeared simultaneously across the whole of southern Scandinavia or if time lags existed between the east and west or *vice versa*. However, the introduction of ceramics in Denmark appears to be contemporaneous with northern Germany suggesting a rapid dispersal in the region (Andersen 2011a). Equally it has been difficult to ascertain whether the lamps or small vessels represented the oldest package of ceramic introduction. Given the absence of prototypes they probably represent a later phenomenon and were constructed a couple of centuries after the pointed based vessels (Brinch Petersen 2011).

5.2.3. Typology of EBK ceramics

5.2.3.1. Pointed based vessels

Pointed based vessels are not just a Danish phenomenon, and have been ubiquitously recovered from localities throughout southern Scandinavia. When encountered they do not form a uniform distribution across each site, and are generally associated with hearths or the discard zone as well as the old settlement surfaces (Figure 5.1) (Andersen 2010). For instance, only 40 pieces were recovered from the Ertebølle kitchen midden that has a chronological range in the region of approximately 1100 radiocarbon years (Andersen 2010, 2011a).

Figure 5.1: In situ sherds from an EBK pointed based vessel on the old settlement surface at the Havnø kitchen midden.

In total, there are <15 complete pointed based vessels from Denmark (Andersen 2010, 2011b). More often sherds deriving from four portions of the vessel are recovered: rim, neck, upper portion (shoulder) and lower portion (belly) terminating in a base (Andersen

2011a). While four different sizes are represented (Table 5.1), the most common are the largest, whereas the small beaker/cup is probably a later introduction and is considered rare (Andersen 2011a; Prangsgaard 1992).

Size/vessel	Height (cm)	Volume (l)	Rim diameter (cm)
Small beakers/cups	08-15	0.5-1.0	05-06
Small vessels	25	1.0-1.5	N.D.
Medium sized vessels	30-35	5.0-15.0	10-15
Large vessels	40-50	15.0-25.0	15-25

Table 5.1: Size, vessel type and typical characteristics (after Andersen 2010, 2011a).

The pointed based vessels were constructed using a lump of clay that was pressed into a cone, onto which clay coils were laid in rings (Nielsen 1986). Each ring was affixed to the one below. Four different construction techniques have been identified, and include the H, U, 'oblique U' and N (Andersen 2010). The H-technique is the most characteristic and has only been identified in EBK vessels.

The EBK vessels are characterized by their coarseness as well as their thickness. They vary from ca. 0.5-2.7 cm. Sherd thickness varies not only according to the size of the vessel but is also spatially and temporally dependent. For example, localities with a long chronological range appear to change temporally, with the earliest and thickest vessels being mainly represented by the H-technique, and the youngest and thinnest vessels by the N-technique. This apparent diachronic change has been identified at both Ertebølle (Madsen *et al*. 1900), and Ringkloster (Andersen 1994-1995, 2010, 2011a).

During their construction they were tempered with red feldspar grains (2-7 mm) that appear to have originated from burnt and crushed granite, perhaps pot-boilers (Andersen 2011a, 2013b). Chamotte, flint, plant material, sand, shells and quartz may also have been occasionally used. The EBK vessels have fewer, albeit larger, tempering particles compared with the TRB and subsequent ceramics (Hulthén 1977; Nielsen 1986). Although there is a complete absence of kilns in the archaeological record, based on experimental analysis it is assumed that they were fired in an open fire at temperatures ranging from 500-600 °C (Hulthén 1977).

The main aspect of variation is related to the shape of the point at the base of the vessel. Pointed, rounded, stud-shaped or double-pointed forms are represented and vary according to the region. At least three different styles have been documented and more than one are often present at each locality (Andersen 2010, 2011a).

In general the pointed based vessels are S-shaped in profile and possessed conical or cylindrical upper and lower portions. A double conical outline is the most common. Necks and rims equally vary although there is a preference for splaying. While the rim is normally everted, straight rims are common and incurving rims have also been identified (Povlsen 2014). Additional variation in vessel shape and size has been observed regionally although there is an absence of evidence in favour of temporal variability (Andersen 2010). In eastern and southern Jutland the pointed based vessels are generally thinner compared to northern Jutland and Zealand. In northern Jutland the vessels are more cylindrical and possessed a rounded bottom and sharp point, while to the south they are characterized by S-shaped profiles and conical bases (Andersen 2011a).

The pointed based vessels generally lack decoration. There is a complete absence of handles, knobs and lugs. However, three different subtle decorative techniques have been identified: incised lines, impressed single or double points, oval figures and even finger nail impressions (Brinch Petersen 2011). In the majority of cases they have been observed on the belly and upper portions of the vessels, and rarely are they present on the interior. Rims with finger nail impressions or notches made from a sharp instrument are present on their edges, and are believed to have been introduced early after their inception, ca. 4500-4400 cal BC (Andersen 2011a, 2013b). However there are a number of sites in east central Jutland where a geometric pattern, often termed as a chequered board style, criss-crossing or a hanging row of dots or simply a mesh, has been identified (Andersen 2010, Brinch Petersen 2011). Similar patterns have been observed on vessels in Skania and northern Germany and may reflect a simple fishnet motif that has been similarly identified on other anthropogenic materials. By contrast EBK vessels from the island of Bonholm and Scania have finger nail impressions across their surface that is different (Andersen 2010, 2011a).

EBK pointed based vessels are either rough, even or smooth, and either brown-black or red-brown in colour, but the colour is dependent upon the portion of the vessel. The interiors of the vessels are always black and some have food crusts. The ceramics recovered from either bog sites or submerged localities are often grey in colour (Figure 5.2) due to the reducing chemical environment (Andersen 2010, 2011a, 2013b).

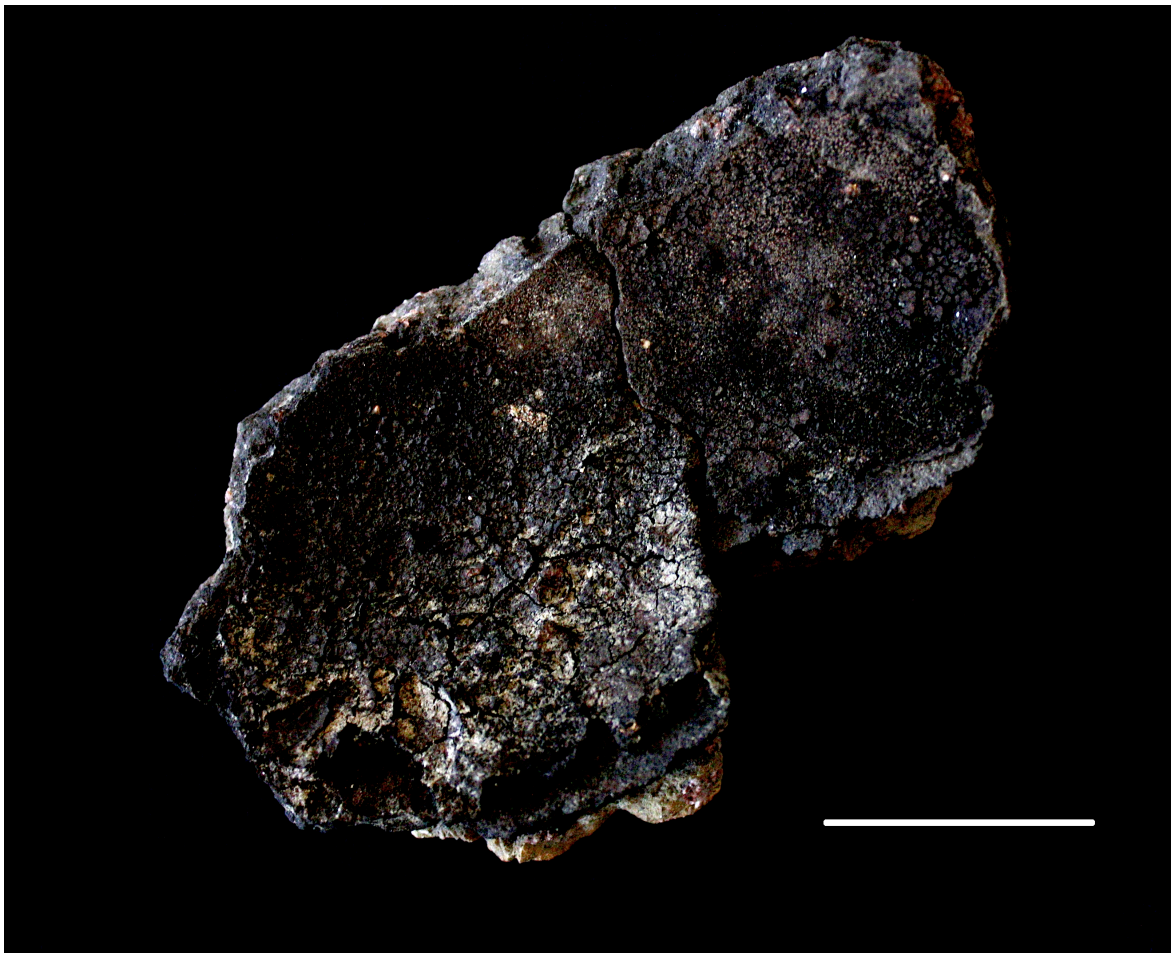


Figure 5.2: Close up of the white surface deposit on the interior of an EBK sherd (AYU) from the submerged site at Ronæs Skov (scale 2.85 cm).

5.2.3.2. Oblong bowls or lamps

Oblong bowls (or more commonly lamps) appear to have been a later construction when compared to the pointed based vessels (Brinch Petersen 2011), and are frequently recovered from sites dating to the younger phases of the EBK (Andersen 2011a). They have a clear south-southeastern distribution in Denmark and have been recovered from both coastal and

inland locations. They are absent from northern Jutland although frequent in northern Germany (Andersen 2011a).

In general, they are rarely recovered from kitchen middens, often only represented by between one and three pieces per site. However, they are frequently encountered at coastal and submerged sites, and have been represented by as many as 15 pieces, for example Ronæs Skov, but there were always fewer than the pointed based vessels (Andersen 2009, 2010, 2011a).

They possess an oblong or oval outline and have pointed or rounded ends (Figure 5.3). In cross section they are usually rounded or symmetrical but some examples with flat bottoms exist (Andersen 2010, 2011a). The lamps vary in size ranging from approximately eight to 30 cm in length, and around two to 15 cm in width. They were built by one of two means, either by coiling as was undertaken for the construction of the pointed based vessels or from a lump of clay (Van Diest 1981). There is an absence of regional and temporal variability (Andersen 2011).

Figure 5.3: Complete lamp recovered from the submerged site at Tybrind Vig (photograph courtesy of Søren H. Andersen, scale 10 cm).

The lamps were constructed from fine-textured chamotte that was mixed with lime and tempered with fine sand, grog or quartzite. This technique differed to that of the pointed based vessels. The rims are generally rounded and they are never decorated *per se*.

However fingernail impressions or hatches made by a sharp edge implement, similar to the other EBK pointed based vessels, are present (Andersen 2010, 2011a). They are often grey-black in colour but some have a red tan (Andersen 2011a). Both the interior and exterior surfaces of the lamps are frequently coated with black soot and food crusts on their ends and the rims (Andersen 2011a). Although numerous uses have been suggested occasionally breaks have been identified and the charring present has indicated that they were continually or secondarily used after they were broken (Andersen 2011a).

5.2.4. Post EBK ceramic production in Denmark

Approximately 800 years after their initial appearance new vessel types represented by thin walls, rounded or flat bottoms and frequent decoration quickly replaced the EBK ceramics, and there are no instances where EBK and TRB vessels are found next to one another (Andersen 2011a). The distinctive typological change is thought to have coincided with the major shift in diet and economic practices including the introduction of domesticated fauna and flora at the onset of the Neolithic, ca. 4000-3950 cal BC (Gebauer 1995; Rowley Conwy 2004; Richards *et al*. 2003a).

Previously the appearance of the TRB vessels had been described as an abrupt typological change (Andersen 2010, 2011a). However, the analysis of ceramics from recent excavations has demonstrated that a gradual change in the wall thickness of the EBK vessels as well as a change in the construction technique occurred. In addition, there are a number of transitional forms between the pointed based vessels of the EBK and the rounded based vessels of the TRB. Typologically narrower rounded bottoms have been found at both coastal and inland locations, for example Bjørnsholm, Krabbesholm II and Ringkloster (Andersen 1975, 1991, 2005). Thus, given the evolving construction technique in the youngest phase of the EBK it has been assumed that the re-introduction of TRB ceramics was a localized and rapid transformation (Andersen 2010, 2011a).

5.2.5. Motivations for adoption and change in pottery

Adoption and change in ceramics was motivated by a change in both the mode and type of foods prepared as well as their use. It has been identified that the design and production of

ceramics was role specific, for example TRB flasks appeared to have held both a depositional and social purpose and were not primarily functional items (Andersen 2010, 2011a; Saul *et al*. 2014).

5.2.6. Chronology and typology of the TRB ceramics

By approximately 3950 cal BC Funnel Beaker ceramics were in use (Figure 5.4). In Denmark the TRB is subdivided into the following four phases: (1) transitional phase, (2) EN I, (3) EN II + MN A I + MN A II, and (4) MN A III/IV + MN A V, which are represented by numerous vessels that are more varied than their EBK counterparts. In general there are four main groups that are summarized as the following:

1) Funnel beakers and slender lugged beakers, including Types 0-VIII, beakers with conical necks and funnel beakers of special type (Type IX).
2) Broad lugged beakers (Types I-III).
3) Bowls including ornamented or unornamented bowls shaped like a spherical segment, ornamented or unornamented funnel bowls, bowls with straight sides and lugs as well as pedestalled bowls.
4) Flasks including lugged jars whereby the lugs are either on the middle of the belly or in a circle around the bottom, unornamented lugged jars with a short neck with either a sack or egged-shaped belly, lugged flasks with a short neck and striped belly, unornamented lugged flasks with a long neck, lugged flasks with a long neck and striped belly, lugged flasks with surface covering ornamentation and ornamented or unornamented collared flasks (Koch 1998).

Overall, the funnel and slender lugged beakers are of primary interest. Based on profile measurements, the former have been divided into Types 0-VIII. Type O funnel beakers are dated to approximately 3950-3850 cal BC, while Types I, II and III from 3850-3500 cal BC (TN I). Types IV, V.1, V.2, VI, VII and VIII are dated to about 3500-2950 cal BC (Phase 3, TN II + MN A I-II), although conical neck beakers appear at the very end of the phase. Type VIII funnel beakers, often unornamented or sparingly ornamented, are dated to the last phase of the TRB, around 2950-2800 cal BC (MN A III/IV + MN A V). In addition,

vessels with conical necks and bucket-formed MN A V-vessels are equally dated to this period (Koch 1998).

Figure 5.4: In situ TRB vessel recovered during the ongoing excavations at Lolland-Falster (photograph courtesy of Theis Zetner Trolle Jensen).

Similarly, the TRB vessels were made of clay that was often tempered with crushed granite. They were constructed from clay coils that were placed on a clay disk. The ceramics were manufactured to a higher quality compared with the EBK vessels and are considered to have played a significant role as items for domestic and intentional depositional purposes. The diameter of the coils is directly correlated with vessel size and ranges from ca. 1.0 to 1.5 cm (Koch 1998).

5.2.7. Function (depositional or functional)

It is worth reiterating that ceramic vessels are cultural artefacts and as such their designs, typologies and use are likely to have been influenced by previous generations including contact and exchange with contemporary groups. Therefore their function should not necessarily be interpreted as a reflection of the local economy (Heron *et al*. 2007). In this section the function of the vessels will be outlined based primary on the archaeological context, ethnographic analogues as well as experimental analyses.

5.2.7.1. EBK vessels

EBK vessels are rarely recovered from contexts indicative of intentional deposition. To date there is only one example where an EBK vessel was recovered in association with an inhumation burial (Asingh 2000). Occasional specimens have been recovered from lake deposits away from the settlement that may represent intentional deposition although this has been hard to prove. Despite this they are often recovered alongside antler and flint axes, amber and animal beads (Koch 1998).

It would appear that the pointed based vessels were chiefly utilized for functional purposes (Andresen 2010) since sherds and pointed bases are frequently recovered from around, and within hearths. For example, at the sites of Flynderhage and Ordrup Naes vessel points were found within layers of ash. It was suggested that they were positioned in a thick layer of embers or hot ashes of an open fire as opposed to the traditional stone fireplaces (Andersen and Malmros 1984). Based on earlier yet similar observations regarding their distribution, experiments have demonstrated that they were used to extract the salt from marine water (Klinge 1932, 1934), and were not primarily used for boiling water. However, this proposition was subsequently disregarded when similar vessels were recovered from inland localities (Mathiassen 1935). More recent experiments have demonstrated that water could have been brought to the boil if a little starch or fat is added. The numerous burnt stones, the so-called potboilers, have been interpreted as aiding this process (Andersen and Malmros 1984). However, pointed based vessels do not necessarily imply a utilitarian function. In agreement with previous analogues (Forchhammer *et al*. 1851) it has been suggested that the EBK ceramics may have been perceived as a symbol for the community that was use during celebrations of gathering and plenty (Whittle 1996, 199).

On the other hand the lamps were originally interpreted as either being used for cooking, heating or illumination based, in part, on comparison with the ceramic or soapstone lamps of the Inuit in the Arctic (Mathiassen 1935). Since the interior of the lamps were described as possessing a greasy look it was assumed that oil from seal, sharks or whales were the most likely sources of fuel (Heron *et al*. 2013; Mathiassen 1935; Noe-Nygaard 1971). Owing to the ethnographic parallels these vessels have become widely known as the

'blubber lamps'. In support of the above, animal fat traces were identified in the clay by Hulthén (1977), although other uses were posited, for example transportable sources of illumination that were primarily used for fishing and sealing from a dugout canoe (Hulthén 1977). Subsequent experimental work on reconstructed lamps by Van Diest (1981) produced a similar pattern of burning or sooting, which led to similar interpretations as those by Mathiassen (1935). More recently, the blubber lamps have been reviewed, which have demonstrated that they were used for the processing of fat from marine and terrestrial mammals or freshwater aquatics (Heron *et al*. 2013) (Appendix 6).

5.2.7.2. TRB vessels

The TRB vessels appear to have been used for two purposes, either functional or intentional depositional, the latter represented by finer wares. Functionally the smaller TRB vessels that are typically called cups have been interpreted as lamps (Troels-Smith 1982; Nielsen 1985). These vessels (rim diameter <15 cm) as well as bowls and flasks were preferentially used for dairy processing, whereas the medium and larger vessels have a more varied use including the processing of marine and plant foods (Saul *et al*. 2014).

Since they are often recovered in hoards in former freshwater environments they represent intentional deposition (Brinch Petersen 2011; Koch 1998). Vessels are usually well preserved in the peat bogs and have been recovered alongside other sacrificial fauna as well as humans. Additional material culture has included flint axes, battle-axes, amber beads and wooden platforms. In general, the find spots of what have been termed 'bog pots' were located near to pronounced features within the landscape, for example hills or small islets. Often they are associated with wooden platforms or stone structures, and usually ca. 2 km from the nearest Megalithic tomb, and in general, near to the settlement (Koch 1998).

5.2.8. What are food crusts?

The term food-crust refers to the charred usually dark organic matter that is often found adhering to either the exterior or more commonly the interior of a ceramic vessel. They are also referred to as deposits or residues and can sometimes be up to several millimeters thick (1-3 mm). The colour is variable from vessel to vessel although black to dark brown to

brownish grey have been documented, and probably reflect differences in the original composition as well as secondary decomposition of the residues. Subsequent experiments using milk have shown that they permeate the vessel wall leaving a dark stain discoloration (Andersen 2013b).

It has generally been accepted that they represent the remnants of foods that have adhered to the vessels during the cooking process (Andersen and Malmros 1984; Fischer and Heinemeier 2003; Isaksson 1997; Nakamura *et al*. 2001; Nielsen 1987; Persson 1997, 1999). When delineated to the upper portions of the exterior of the vessels, it has been suggested that this was a result of the contents boiling over, whereas the lower portions may have dried out by the heat from the fire that would have burnt the food remains away. This proposition has been supported by experimental analyses (Andersen 2013b; Andersen and Malmros 1984; Koch 1987, 1998).

5.2.8.1. EBK food crusts

In general the interior of the EBK vessels are always black and some possess well-preserved food crusts. They are often located along the rim and on the neck (Andersen and Malmros 1984). However, soot blackened vessel sides and food crusts are not as common on the exterior. When present they are generally distributed on the necks, although they have been identified from the rim to the base. In comparison both the exterior and interior surfaces of the lamps are frequently coated with black soot and food crusts that are usually deposited on their ends and rims (Andersen 2011a; Andersen and Malmros 1984; Saul et al. 2014).

5.2.8.2. TRB food crusts

Similarly the TRB vessels possess food crusts both on their interior and exterior. On the exterior they are likewise to be found on the upper portions of the vessels but have a more localized distribution on the rim and upper body (Saul *et al*. 2014). In addition, another thinner and glossy coating has been identified that probably reflects the soot from the open fire when in use (Koch 1998). It has been suggested that the variability is probably a reflection of the preparation techniques of particular foods (Saul *et al*. 2014).

5.3. Organic residue analysis from ceramics

5.3.1. Brief overview of analysis of lipids from ceramics

The inception of lipid analyses during the last two decades for the characterization of organic residues has been instrumental for determining food and non-food products (Evershed 2008; Evershed *et al*. 2001). Lipids encompass a range of compound classes, although the majority of research has been carried out on fatty acids since they are the largest constituent of fats and oils and preserve well (Heron and Craig 2011; Heron *et al*. 2007). There have been a number of issues regarding the identification of organic substances when only distributions of fatty acids are available (Heron and Evershed 1993). These result from their presence in many food sources, composition variability according to diet, climate as well as the preferential degradation of unsaturated fatty acids and diagnostic short-chained fatty acids since deposition (Heron and Craig 2011). Consequently it has been difficult to discriminate between the wide-ranging potential sources of degraded lipid residues comprising fatty acids (Heron and Craig 2011; Heron *et al*. 2007). Identifications based, in part, on specific fatty acids restricted to specific biological sources have been made (Copley *et al*. 2005a).

Recently the use of GC-C-IRMS has made it possible to discriminate between degraded fats and oils. The technique ascertains the carbon ($\delta^{13}C$) isotope values of the most abundant unsaturated fatty acid components ($C_{18:0}$ and $C_{16:0}$) as well as other lipids. Its use has allowed the differentiation of lipids of different biosynthetic origin, for instance freshwater from marine, ruminant from non-ruminant, and adipose from diary in ceramic vessels. For this study the analyses performed on authentic reference fats from northern Europe has been collated. These data are plotted in Figure 5.5 and are listed in Appendix 4. In general, the reference ellipses have corresponded well with the archaeological residues from which the use of the vessel can be inferred (Copley *et al*. 2005b; Craig *et al*. 2005a, 2005b, 2011, 2012, 2013; Evershed *et al*. 2001, 2002; Taché and Craig 2015).

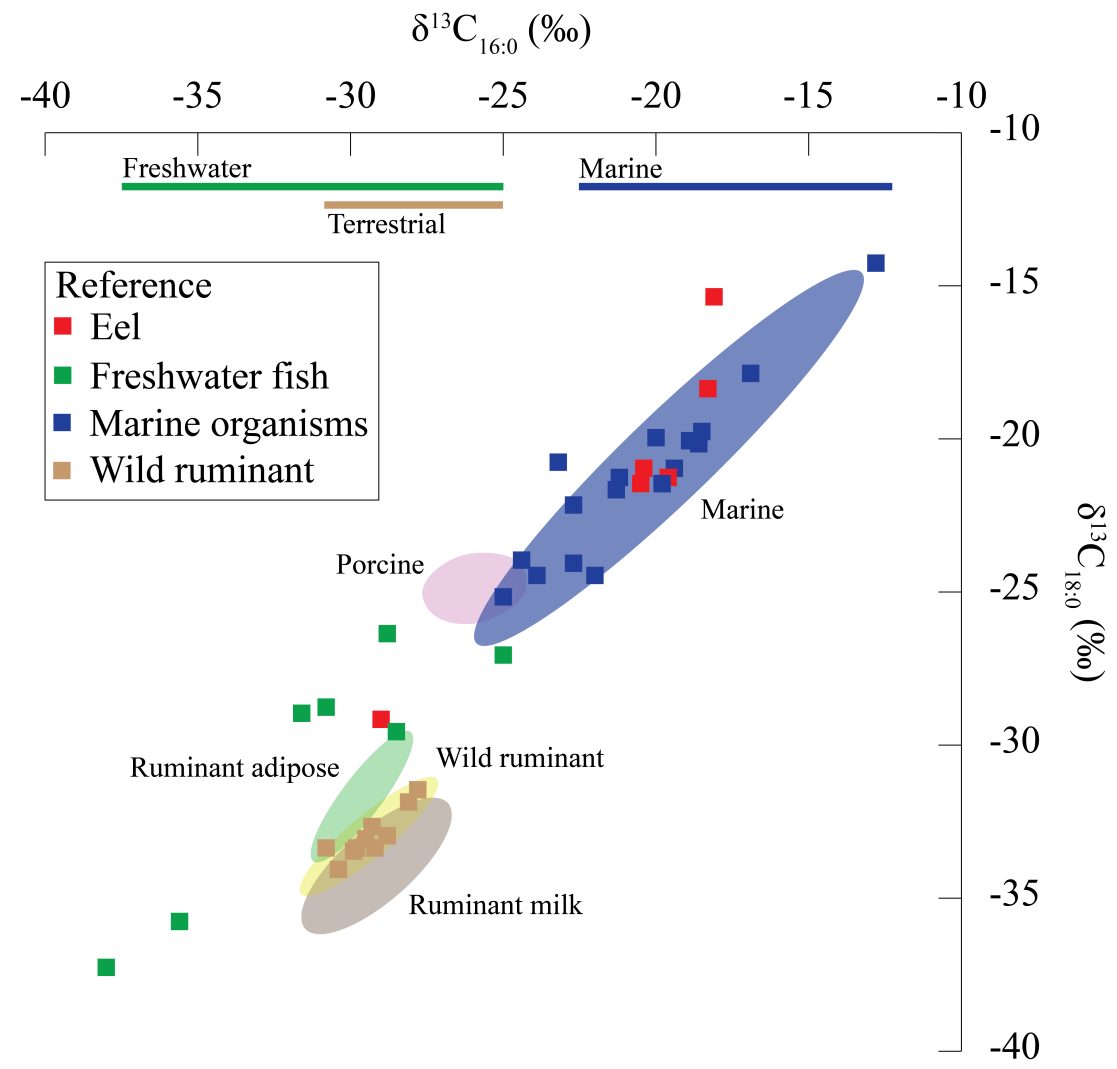


Figure 5.5: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from authentic reference fats. The eel and freshwater (pike, carp, tench and soft tissue) taxa were caught in Danish or UK coastal waters, rivers and lakes, the majority of which has been published (Craig et al. 2011). Owing to the large range in the $\delta^{13}C$ values a freshwater ellipse was not attempted. The marine organisms (Atlantic herring, Atlantic cod, Atlantic mackerel, shorthorn sculpin, eelpout, European plaice, flounder, European oyster, spotted seal and harbor seal soft tissue or blubber) derived from similar localities (Craig et al. 2011). The wild ruminant, represented by red deer bone derived from Poland (Craig et al. 2012), whereas the porcine data have been published elsewhere (Dudd and Evershed 1998). These data were plotted with 95% confidence ellipses in Microsoft Excel and digitalized in Adobe Illustrator.

In addition, it has been recently demonstrated that identifications can be made by comparison of the $\delta^{13}C_{16:0}$ values with the $\Delta^{13}C$ ($\delta^{13}C_{18:0}$ - $\delta^{13}C_{16:0}$) values (Craig *et al.* 2012). In their study the criteria for the identification of dairy products was revised, and

carcass fats from wild ruminants were taken into consideration. These criteria have, in part, aided in the interpretation of dairy residues that had been identified on some EBK ceramics (Saul *et al*. 2014). However, the presence of dairy could conceivably represent exchange between coastal foragers and other early farming groups to the south, or perhaps the exploitation of dairy products from wild ruminants *post mortem*, for example red or roe deer, or even earlier domestication. Despite the lack of faunal or aDNA evidence supporting domesticates in EBK assemblages, one *Sus* sp. from Grube-Rosenhof, northern Germany has been hotly debated (Evin *et al*. 2014; Krause-Kyora *et al*. 2013; Rowley-Conwy and Zeder 2014a, 2014b).

The degree of characterisation is not just a reflection of technical advancement, and is largely the result of specific research designs, increased sample sizes as well as the consideration of all lines of evidence (Heron and Craig 2011; Heron *et al*. 2007). In addition, it must be borne in mind that the identification of vessel use is not straightforward, for instance some foodstuffs without a prominent lipid fraction maybe underrepresented in the surviving organic residue (Heron and Craig 2011). Furthermore, foodstuffs are likely to have mixed, therefore representing a combination and not necessarily a single processing event. Conceivably they may also have been used for other purposes. Lastly degradation and contamination should be taken into consideration (Heron and Craig 2011).

5.3.2. Identification of freshwater and marine fats and oils

The first claims for the detection of freshwater and marine lipids from ceramic residues were made in the 1980s (Needham and Evans 1987; Rottländer and Hartke 1982), and were based on the original fatty acids. These interpretations have been questioned given the lack of sufficient data (Heron and Evershed 1993). In a subsequent publication lipids characteristic of mammal tissue and/or marine fat were identified in an organic residue associated with a ceramic sherd (Patrick *et al*. 1985). The analyses demonstrated polyunsaturated fatty acids (PUFAs) were degraded in the archaeological material, but monounsaturated species, including nervonic acid (tetracosenoic, $C_{24:1}$) were preserved. Experimental analyses utilising seal tissue found that the fatty acid composition was similar

to the archaeological material.

A further renowned study identified monounsaturated fatty acids in abundance from fatty matter deriving from a Thurle Inuit Arctic midden (Morgan *et al*. 1984). Since long-chain (C20 and longer) unsaturated fatty acids were present, the matter was indicative of marine mammals. Marine fish or mammal was represented by gadoleic acid (eicosenoic acid, $C_{20:1}$), but the reduced levels of behenic acid (docosenoic acid, $C_{22:1}$) were interpreted as fat representing either seal or whale.

A relatively recent study included the lipid analyses of potsherds from a number of sites in western Canada, and resulted in the identification of freshwater species of fish by comparison with a reference collection comprising of experimental analyses (Malainey *et al*. 2001). The relative abundance of medium ($C_{12:0}$, $C_{14:0}$ and $C_{15:0}$) and long chain fatty acids ($C_{18:0}$ and $C_{18:1}$ isomers) were identified as deriving from fish.

Despite these studies there was, in general, a lack of research on the recognition of the degradation products of fatty acids (Evershed *et al*. 2008), including fats and oils of marine origin, which had been considered difficult to detect in the organic residues of ceramic vessels (Brown and Heron 2005; Patrick *et al*. 1985). Thus, the research by Copley *et al*. (2004) and Hansel *et al*. (2004) has been instrumental for the characterisation of animal products of marine origin. In these studies coastal sites in Brazil and South Africa were sampled, and demonstrated the presence of phytanic acid (3, 7, 11, 15-tetramethylhexadecanoic acid), and 4, 8, 12-trimethyltridecanoic (4, 8, 12-TMTD) acid in several ceramic vessels. Although these isoprenoid compounds are present in low concentrations of terrestrial animals, they have high concentrations in marine mammals (Ackman and Hooper 1968). In addition, the study by Hansel *et al*. (2004) demonstrated the presence of ω-(o-alkylphenyl)alkanoic acids, which are produced from the protracted heating of tri, di-, or monounsaturated fatty acids from the oils of marine organisms. Thus, their presence provided unequivocal evidence that the ceramic vessels had been used for the processing of animal products of marine origin. Furthermore, experimental analysis has established a number of criteria that should be observed in order to confirm the presence of

lipids of aquatic origin in ceramic vessels. The presence of ω-(o-alkylphenyl) alkanoic acids of carbon chain length $C_{18:0}$, $C_{20:0}$ and $C_{22:0}$ together with at the very least one of three isoprenoid fatty acids were stated (Evershed *et al*. 2008).

Despite the continued use of GC-C-IRMS it is not yet possible to differentiate between marine resources on ceramics. The main reason is that it has been difficult to distinguish between isotopic signatures from fatty acids of known samples, for example marine fish and pig adipose tissues (Evershed *et al*. 2002). Therefore the combination of GC-C-IRMS data and specific biomarkers has recently provided an alternative strategy (Craig *et al*. 2007).

5.3.3. Application of ORA to ceramic shards from Danish kitchen middens

Despite the comprehensive analyses undertaken on EBK and TRB sherds from Denmark (Appendix 4 and Table 5.2) the application of ORA to ceramic sherds recovered from the Danish kitchen middens is restricted to two studies.

Analyses undertaken	**Reference**
Use wear	Madsen *et al*. 1900
ORA	Biilmann and Jensen in Mathiassen 1935
Bulk $\delta^{13}C$ isotope/macrofossil	Andersen and Malmros 1984
ORA	Arrhenius and Lidén 1989
Bulk $\delta^{13}C$ and $\delta^{15}N$ isotope/macrofossil	Koch 1998
Bulk $\delta^{13}C$ isotope	Fischer and Heinemeier 2003
Bulk $\delta^{13}C$ isotope	Richter and Noe-Nygaard 2003
ORA	Craig *et al*. 2007
Macrofossil	Andersen 2009
ORA	Craig *et al*. 2011
ORA	Heron *et al*. 2013
Microfossil	Saul *et al*. 2012, 2013

Table 5.2: Analyses undertaken on Danish EBK and TRB ceramic vessels in chronological order.

In the first study Heron *et al*. (2007) sampled 33 ceramic sherds that were recovered from the Bjørnsholm and Norsminde kitchen middens. The vessels were assigned as either EBK or TRB according to location within the kitchen midden as well as typology. Lipids were

solvent extracted and GC, GC-MS and GC-C-IRMS analyses were performed. Fatty acids were present but acyl lipids were absent that suggested to the authors that lipid hydrolysis had taken place during deposition. Lipids were preserved in sherds from both Bjørnsholm (*n* = 5/15) and Norsminde (*n* = 13/18). The major components included saturated fatty acids ($C_{16:0}$ (hexadecanoic), $C_{18:0}$ (octadecanoic)), which was expected since unsaturated fatty acids ($C_{18:1}$, $C_{18:2}$) rapidly degrade (Heron *et al*. 2007).

One of the major findings of the study was the absence of contamination. While it was suggested that there was minimal migration of lipids from the surrounding organic matrices to the deposited sherds, post depositional contamination should always be borne in mind (Heron *et al*. 1991, 2007; Stott *et al*. 2003). Thus, it was suggested that the preserved lipids were related to function. In support of the above appreciable quantities of ω-(o-alkylphenyl)alkanoic acids demonstrated direct heating of fish oils in the vessels (Hansel *et al*. 2004). Due to the complete absence of food crusts the lipids had absorbed into the ceramic surface during use. The majority of the sherds contained $C_{16:0}$ and $C_{18:0}$ in broadly equal proportions. These components are indicative of animal products since vegetable lipids are depleted in $C_{18:0}$ (Enser 1991). Odd-carbon number fatty acids ($C_{15:0}$, $C_{17:0}$) and branched versions of these were additionally identified. These are typically prevalent within ruminant animal tissues. Unfortunately there was an absence of acyl components, sterols and other distinctive fatty acids and so the authors were not able to further interpret vessel use (Heron *et al*. 2007).

Several samples were analysed by GC-C-IRMS although these data were not plotted. Instead the values were labeled on the three gas chromatographs deriving from three TRB vessels from Bjørnsholm. These data demonstrated to the authors that different animal products with variable isotopic values had been processed. In sum, foodstuffs of marine origin had been processed in sherd AMBR, whereas terrestrial animal products, probably ruminant or dairy fats were identified in sherd ACEK. In support of the above a branched odd chain fatty acid was present in sherd ACEL. In addition, non-food organic substances were identified. Notably, beeswax was present in a sherd from Bjørnsholm (UAR) and reference was made to an EBK sherd from the nearby kitchen midden at Åle. In addition,

isotope measurements indicated a mixture of marine, dairy, and non-ruminant based products were processed in these vessels. To summarise, the authors emphasised that ceramics interred in kitchen middens are suitable for ORA, and offer the opportunity to identify foodstuffs that were previously unknown, for example beeswax and dairy (Heron *et al*. 2007).

Unfortunately the second study (Heron and Craig 2011) has limited use. While it expands on the previous study (Heron *et al*. 2007) the time taken from submission to publication makes the majority of the data outdated, although there are a number of important points that are not discussed elsewhere (Craig *et al*. 2007, 2011; Heron *et al*. 2007, 2013). Notably preservation was variable and lower levels of lipids were identified on the sherds recovered from the kitchen middens compared with submerged and waterlogged localities. In addition Heron and Craig (2011) state that at least 72 vessels from five Danish kitchen middens were sampled: Åle (n = 10), Bjørnsholm (n = 18), Ertebølle (n = 10), Norsminde (n = 15) and Visborg (n = 9). Unfortunately the data has not been comprehensively published, and so there is no way of knowing whether GC, GC-MS or GC-C-IRMS was performed on all of the sherds.

Owing to the caveat of ORA from sherds recovered from the Danish kitchen middens the present study is more the important. Presently the dataset is restricted to 12 sherds from three localities: Åle (n = 1), Bjørnsholm (n = 9) and Norsminde (n = 2) (Craig *et al*. 2011; Heron *et al*. 2007). Of these, only one sherd has been dated to the EBK (Åle), whereas those from Bjørnsholm (n = 9) and Norsminde (n = 2) to the TRB. The initial analysis by Heron *et al*. (2007) on the Bjørnsholm and Norsminde sherds was based on the assumption that they derived from both the EBK and TRB. However, subsequent analysis demonstrated that only TRB vessels are represented (Craig *et al*. 2011).

5.4. Previous sampling strategies

On the whole ceramics are recovered alongside other anthropogenic material including antler, bone, lithics and features including hearths and postholes within the Danish kitchen middens. Since these localities have thick cultural layers, high stratigraphic resolution, old

surface and activity areas as well as good conditions for preservation (Andersen 2011a) they offer the best opportunity for analysing the degree of Neolithisation by the earliest pastoralists of Denmark through ORA (Andersen 1989, 1991, 2005).

For the majority of ORA studies, the sample size has largely been dictated by budgetary constraints as well as the availability of samples at that time (Craig *et al*. 2007). In addition, sherds with adhering food crusts have often been preferentially selected (Craig *et al*. 2011; Saul *et al*. 2014). Consequently ceramic vessels derived from kitchen middens are underrepresented within the overall dataset for southern Scandinavia. Although it has been demonstrated that the ceramic vessels did not reflect a change in the use of marine resources at this time (Craig *et al*. 2011), (Figure 5.6), to date a systematic study including both EBK and TRB ceramic vessels from the one kitchen midden has not been undertaken.

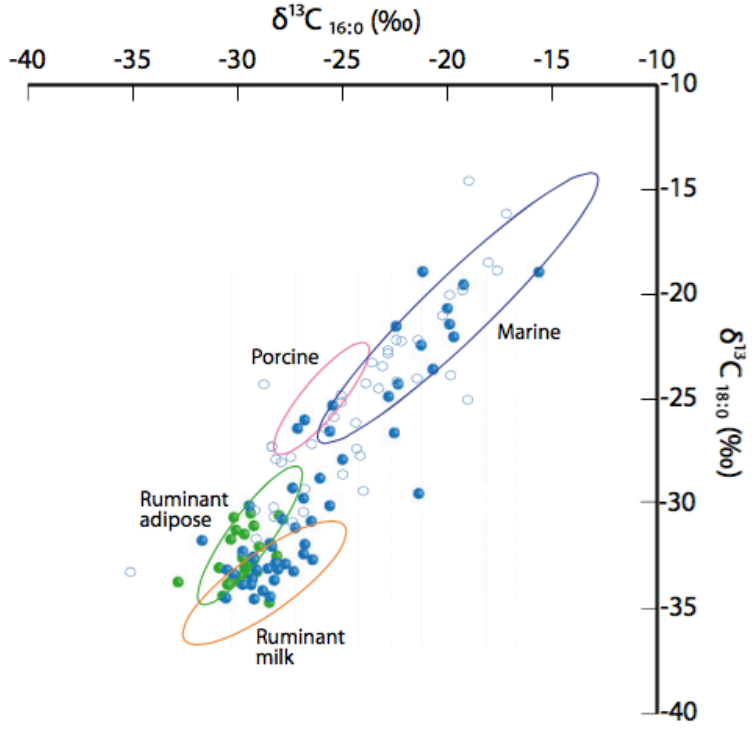


Figure 5.6: Compound-specific stable isotope analysis of adhering food crusts from EBK (open circles) and TRB (closed circles) vessels from coastal (blue) and inland (green) sites throughout southern Scandinavia (Craig et al. 2011).

5.5. ORA of ceramic sherds from Havnø

5.5.1. Sampling

For the present study 27 sherds were obtained for ORA from the Havnø kitchen midden. The goal of the sampling strategy was to analyse sherds typical of the EBK and TRB cultures to evaluate temporal change, as well as from different locations throughout the kitchen midden to assess spatial variability. Initial sorting of the sherds was undertaken in Denmark, and they were sent to the University of York in 2013. Prior to lipid extraction the sherds were analysed with Hayley Saul to determine a number of characteristics: weight (g), interior curvature (cm), sherd edge (%), construction technique, temper, wall thickness (cm), profile, vessel type, coil thickness (mm), and confidence (%). In addition, notes on the temper, the presence of fingernails and surface residues were made. Refitting was attempted and was successful for five of the sherds. All of the aforementioned were taken into consideration for typological assignation.

Of the 27 sherds, 10 were typologically assigned to the EBK and eight to the TRB (Appendix 4). It was not possible to ascertain or assign the remaining nine samples to period or culture. In total, 22 sherds (Table 5.3) deriving from 15 different grid squares (Figure 5.7) were selected for ORA. Absorbed lipids were extracted from pointed based vessels (n = 10) and rounded or flat-based beakers (n = 8) of the EBK and TRB cultures respectively (Figures 5.8 and 5.9). In addition, four sherds that could not be differentiated typologically, but probably dated to the TRB given their location within the midden sequence and wall thickness were included. Furthermore, two carbonized food crusts, one each from an EBK and TRB sherd were selected for ORA.

Finds no.	Curvature (cm)	Vessel type	Construction technique	Temper	Part of profile	Traces of surface deposits	Decoration
DAO	17	Large	H or U	Pink granite	Body sherd	No	Fingernail impressions present
DGX	15	Medium sized	H	Pink granite	Body sherd	No	
FAF	12	Medium sized (slight flare)	N	Pink granite	Upper body/ neck/ rim sherd	No	
FAJ	11	Medium sized	H, N	Pink granite	Body sherd	No	
FBF	n/a	Unknown	H	Pink granite	Body sherd	Thin black deposit on the interior	
HXZ	8	Small	U, N	Pink granite	Body sherd	No	
PCE	13	Medium sized	H	Pink granite	Body sherd	No	Fingernail impressions on the coil
SLG	14	Medium sized	N or U (cf. N)	Pink granite	Body sherd	No	
TBU	20	Large	H	Pink granite	Body sherd	No	
TEW	11	Medium sized	H	Pink granite	Body sherd	Thin black deposit on the interior	
TU	16.5	Jar or globular	N	Pink and white granite	Body sherd	No	
AQA	12	Unknown	U	Pink granite	Body sherd	No	

Finds no.	Curvature (cm)	Vessel type	Construction technique	Temper	Part of profile	Traces of surface deposits	Decoration
AQH	18	Unknown	N	Pink and white granite	Body sherd	No	
JQT	10	Jar or globular	N	White granite (very fine)	Lower body sherd	No	
LMM	18	Flared	N	White and pink granite (mostly white)	Neck sherd	Thin black deposit on the interior	
LUQ	22	Jar or globular	N	Pink granite	Body sherd	No	
MDP	17	Unknown	N	Pink and white granite (fine)	Lower body/ base sherd	No	
XXQ	21	Unknown	N	Pink and white granite	Body sherd	No	
ACAB	7	Unknown	N?	Pink granite	Upper body/ neck sherd (larger)	No	
UOL	17	Unknown	N	Pink granite	Sherd (cf. neck)	No	
AFCW	3	Drinking cup (slight flare)	N	No visible temper	Sherd (cf. neck)	No	
AFCW_II	7	Unknown	N	No visible temper	Rim sherd	No	Incised decoration on the exterior edge of the rim (Koch 1998, 100); square edge at point of decoration

Table 5.3: Sampled ceramics from the Havnø kitchen midden. Curvature represented the interior of the vessel. Vessel type was based on the rim diameter. In addition, sherd edge (%), coil thickness (mm), and confidence (%) were recorded although are not reported here (see Appendix 4). Wall thickness (cm) is absent as it is expressed in Figure 5.10 (see text).

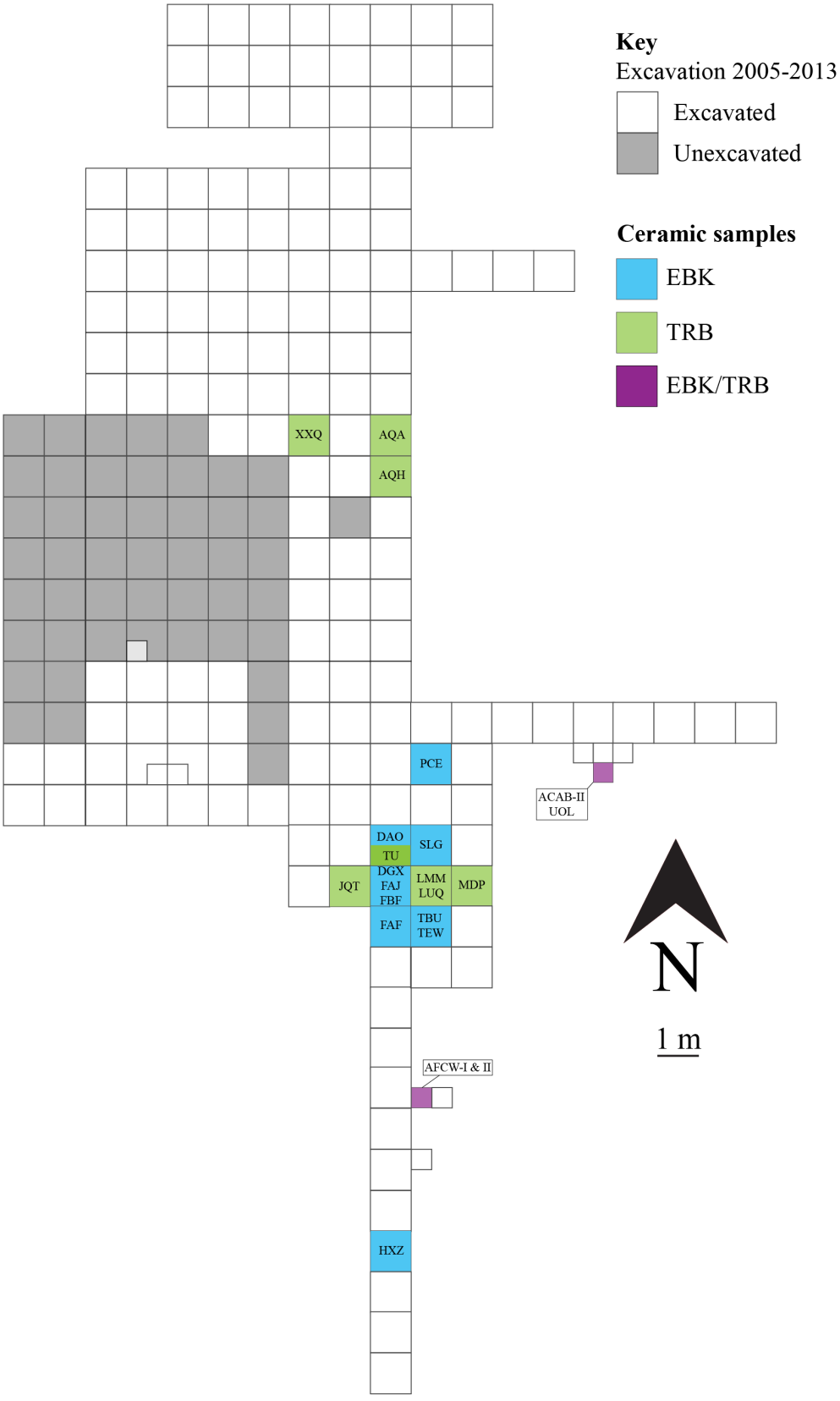
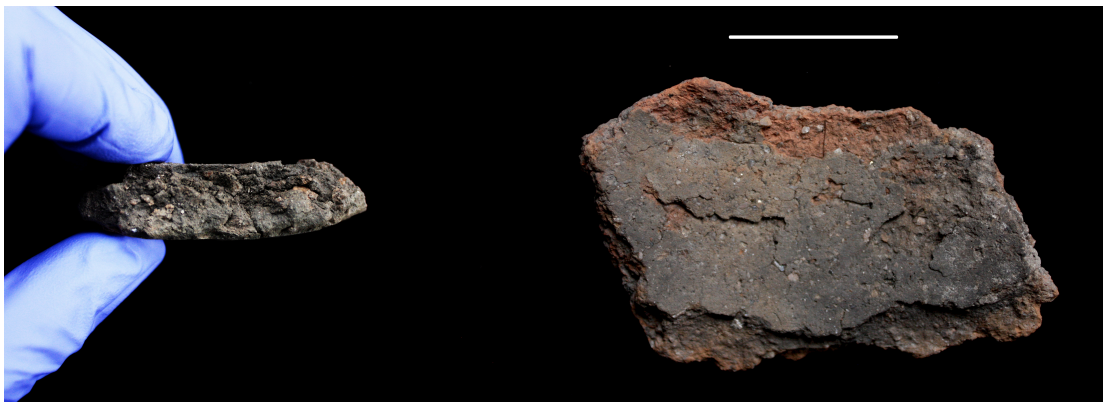


Figure 5.7: Locations of the sampled ceramic sherds.



Figures 5.8 and 5.9: Photographs of an EBK (left) and TRB (right) sherd recovered from Havnø (scale 3 cm).

As has been previously demonstrated (Andersen 2009, 2013b) the wall thickness of the EBK sherds was greater than those from the TRB and subsequent cultures (Figure 5.10). At Havnø the EBK vessels had a mean wall thickness of 1.5 ± 0.1 cm (n = 10), whereas the TRB ceramics had a mean wall thickness of 0.8 ± 0.1 cm (n = 8). The four sherds that could not be typologically dated had a mean thickness of 0.8 ± 0.1 cm that is consistent with the TRB sherds.

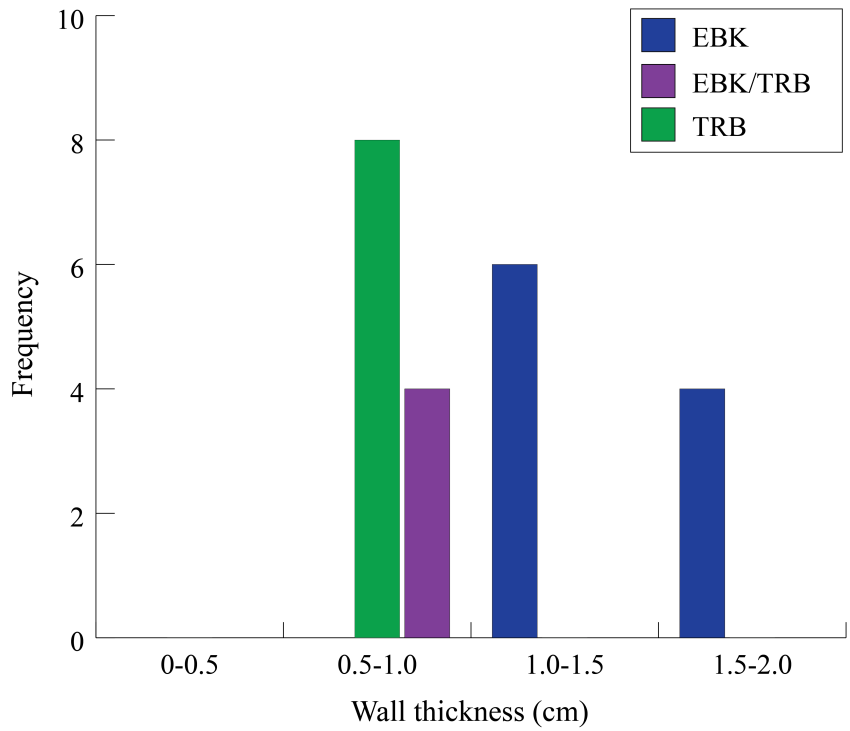


Figure 5.10: Wall thickness of the sampled sherds. Note the four sampled sherds that are probably TRB based on their location within the midden sequence and wall thickness.

5.5.2. Inter-site comparison

For inter-site comparison a number of ceramics from two kitchen middens and four coastal settlement sites were sampled in order to enhance our understanding of the types of foods processed during the EBK and TRB cultures of Denmark (Figure 5.11). Absorbed lipids were extracted from EBK (Åle and Teglgård-Helligkilde) and TRB (Bjørnsholm) sherds as well as nine charred food crusts (Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde, and Tybrind Vig).

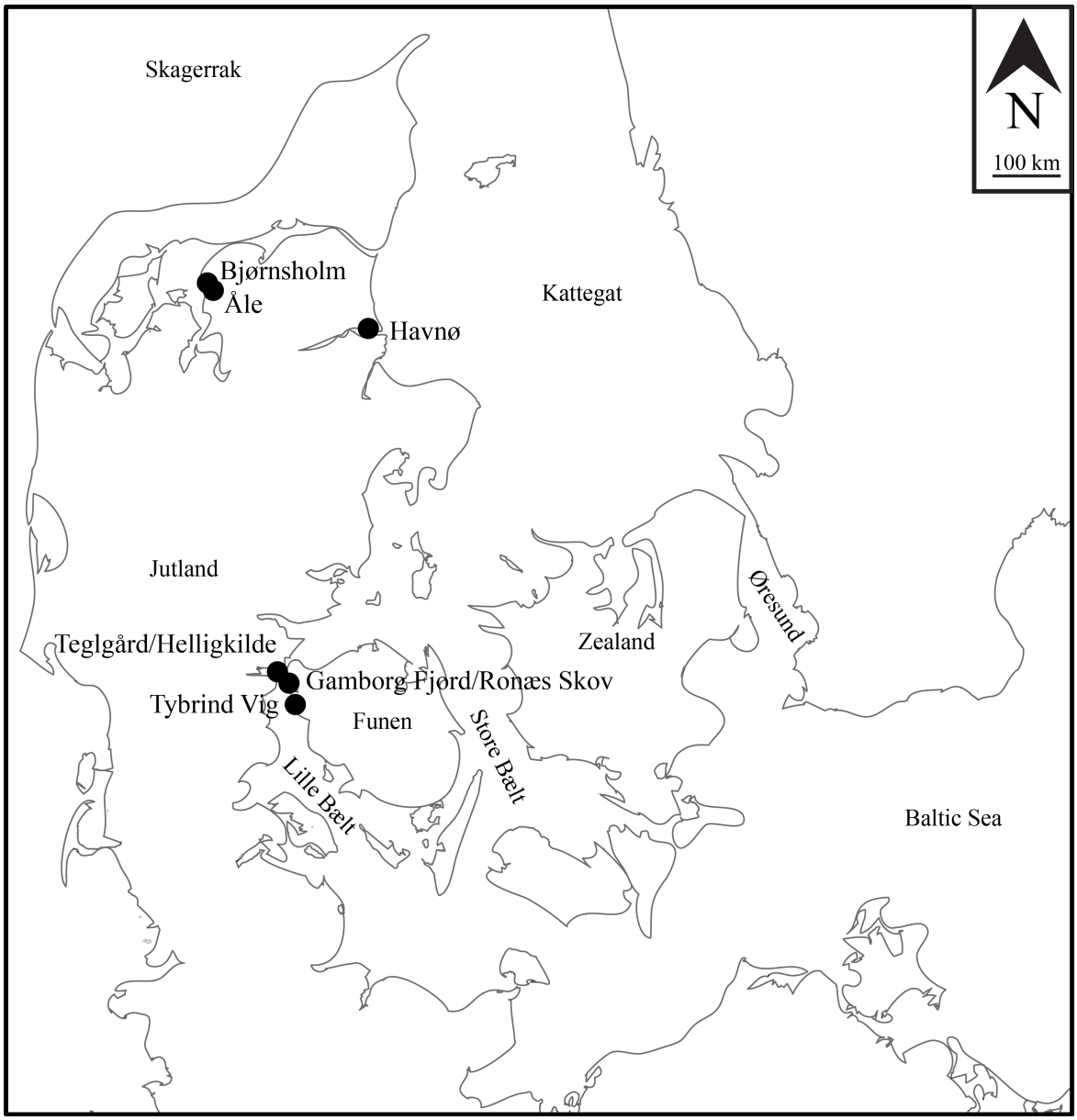


Figure 5.11: Map of Denmark showing all of the sites sampled in this study.

5.5.2.1. Åle

One EBK sherd from the Åle kitchen midden that had not been previously sampled was included.

5.5.2.2. Bjørnsholm

Similarly two TRB sherds from the stratified kitchen midden at Bjørnsholm were sampled.

5.5.2.3. Gamborg Fjord and Ronæs Skov

In April 2014 one isolated sherd recovered from the seabed in Gamborg Fjord and five vessels from the submerged settlement at Ronæs Skov were sampled. The vessels were selected based on a number of criteria including affiliation to cultural epoch and typology. All six sherds derived from large sized EBK vessels. Since the food crusts on the six ceramic vessels were relatively thick, >1.0 mm (Figure 5.12), they were sampled as opposed to a portion of the sherd because the latter would have been destructive.

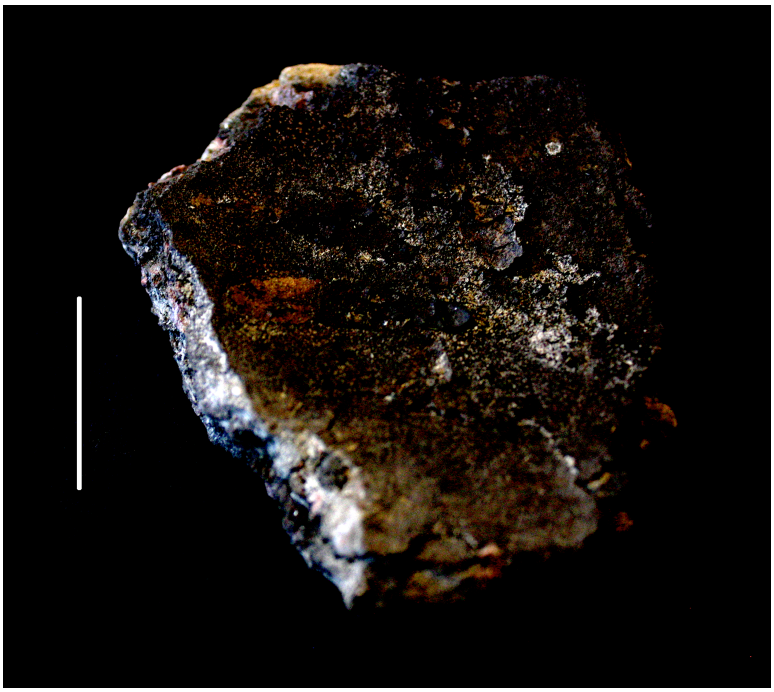


Figure 5.12: Carbonized food crust adhering to the interior of an EBK vessel (AWJ) recovered from Ronæs Skov (scale 2.82 cm).

5.5.2.4. Teglgård-Helligkilde

The two Teglgård-Helligkilde samples were extracted from the same EBK lamp (Figure 5.13) that had been previously analysed (Craig *et al*. 2011; Heron *et al*. 2013). Due to the

relatively small portion of the ceramic vessel remaining lipid extraction was attempted. Since the %N data reported by Heron *et al*. (2013) was considered to be too low, the remaining residue sample that weighed <10 mg was selected for EA-IRMS analysis only.

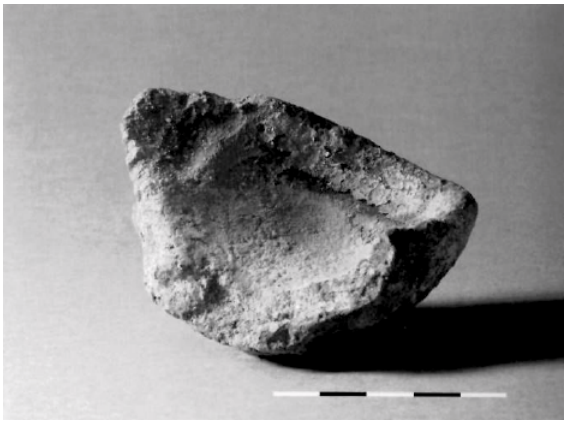


Figure 5.13: The EBK lamp sherd from the Teglgård-Helligkilde submerged locality (after Andersen 2009, 190).

5.5.2.5. Tybrind Vig

In addition, two food crusts adhering to two EBK vessels that were recovered from Tybrind Vig were chosen for lipid extraction, and of these one was selected for EA-IRMS analysis.

5.6. Methods

In order to achieve the two primary objectives several analyses were undertaken: (1) bulk carbon and nitrogen stable isotope analysis of carbonized surface residues using Elemental Analysis-Isotope Ratio Mass Spectrometry (EA-IRMS), (2) Gas Chromatography (GC) to confirm the presence or absence of lipids, calculate the lipid concentrations present and quantify the yield, (3) Gas Chromatography-Mass Spectrometry (GC-MS) to identify specific biomarkers of individual fat components, and distinguish between animal and plant sources as well as known degraded products of fish (freshwater and marine) and mammal oils, and (4) Gas Chromatography-Combustion-Isotope Ratio Mass Spectrometry (GC-C-IRMS) to identify lipids of different biosynthetic origin.

In the following a summary of the aforementioned analyses will be provided, whereas the Standard Operating Procedures (SOPs) for acid extraction of organic residues from archaeological ceramics as well as food crusts preserved on archaeological ceramics at The

University of York can be found in Appendix 4.

5.6.1. EA-IRMS

Bulk $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis was performed on the visible food crusts, which had been removed using a sterile scalpel from the exterior or interior surface of the vessels where present. The samples were not pre-treated prior to analysis, for instance for the removal of humic and fulvic acids. However, even if this procedure had been undertaken, several authors have highlighted that while this has minimal effect on the $\delta^{13}C$ values (Morton and Schwarcz 2004), it would likely dissolve and remove the components of the original foodstuff (Segeberg *et al*. 1991). Each sample was dried and weighed in duplicate (between 0.8 and 1.2 mg) into tin capsules for elemental analysis in a Sercon GSL analyser coupled to a Sercon 20-22 Mass spectrometer (PDZ-Europa, Crewe, UK) at the University of York. Following standard procedure the samples were measured relative to the Vienna Pee Dee Belemnite (V-PDB) and atmospheric nitrogen (AIR) international standards for $\delta^{13}C$ and $\delta^{15}N$ respectively using a number of laboratory standards traceable to international isotope reference standards. Each element was analysed individually, as the amount of C in the food crusts was often far in excess of the amount of N. This was based, in part, on the nature of the sample that represents the remnants of foods that have adhered to the vessels during the cooking process. All samples were determined in duplicate and the results averaged (Craig *et al*. 2007, 2011, 2013; Heron *et al*. 2013). Samples yielding <1% (N) were discarded and excluded from any further analysis (Craig *et al*. 2013). Analytical error, calculated from the repeated measurements of each sample and measurements of a bovine standard from multiple extracts, was <0.2% (1σ).

5.6.2. Lipid extraction

To avoid contamination nitrile gloves were worn at all times. All glassware and tools were solvent rinsed (x 3 in DCM) between samples or sterile (450ºC for 6 hours) and all reagents were of Analar or HPLC grade.

Visible charred food crusts were removed by removing approximately 20 mg of the residue using a sterile scalpel from the surface of the vessels (where present) onto aluminum foil.

The sample was then transferred to a clean-labeled glass vial. Between 10-20 mg of the food crust was then accurately weighed into a clean-labelled glass scintillation vial. Methanol (1 ml) was added to the homogenized charred surface deposits and the residue was ultrasonicated for 15 minutes and then acidified with concentrated sulphuric acid (200 µl).

To extract absorbed residues a small portion of the surface of the sherd was cleaned using a Dremel modeling drill fitted with tungsten carbide tipped bit, and then approximately 1 g was removed from either the exterior or interior surface using the same drill by drilling to a depth of between 2 and 4 mm onto aluminum foil. The sample was then transferred to a clean-labeled glass vial. The sample was homogenized in a solvent-washed mortar and pestle. Approximately 1 g of the sherd powder was then accurately weighed into a clean-labeled glass Hach tube. Methanol (4 ml) was added to the homogenized sherd powder and the mixture was ultrasonicated for 15 minutes and then acidified with concentrated sulphuric acid (800 µl).

The acidified suspensions were sealed and heated at 70°C for 4 hours on a heating block and then cooled. All samples were then centrifuged for 5 minutes. The liquid extract was carefully pipetted into a clean-labeled glass Hach tube. To extract the lipids, 2 ml of hexane was added to the Hach tubes, which were then placed on a vortex. Once the hexane layer had separated, it was pipetted off carefully into a clean-labelled glass Hach tube through a prepared Pasteur pipette, as explained hereafter. To remove any traces of sulphuric acid in the hexane extract, a Pasteur pipette was packed with glass wool (enough to plug the pipette) and approximately 5 mm of cleaned potassium carbonate (K2CO3) was added. To clean, between 1 and 2 ml of DCM was passed through it. In total, the same extraction procedure was undertaken three times and the lipid extracts were combined. Finally 1 ml of hexane was passed through the pipette. The extracts were blown to dryness using a very gentle flux of dry nitrogen (N2) and gentle warmth (40°C). The samples were then re-suspended by adding 90 µl of Hexane with a syringe and rolled ensuring that the whole extract was suspended (including the neck). The 90 µl of Hexane and extract was then transferred to a clean-labeled auto-sampling vial with a 0.1 ml conical insert using a Pasteur

pipette or syringe and combined with 10 µl of the C36 alkane standard (n-hexatriacontane). The lipids were then directly analysed by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) using standard protocols at the University of York.

A mixed $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ standard was methylated with each batch of samples to allow correction of the GC-C-IRMS results for the carbon atom added to each molecule during methylation. The carbon isotopic value of unmethylated samples of the same $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ fatty acids had previously been measured (Colonese *et al*. 2014; Craig *et al*. 2007, 2012, 2013; Hansel *et al*. 2004).

5.6.3. GC-FID analysis

The majority of the extracted lipids were analysed by GC using an Agilent 9890A gas chromatograph (Agilent Technologies, Cheadle, UK). The injector was splitless and maintained at 300°C that injected 1 µl of the sample into the GC. A 100% Dimethylpolysiloxane DB-1 (15 m x 320 µm x 0.1 µm) column was used. The carrier gas was hydrogen that has a constant flow rate of 2 ml/min. The temperature program was set at 100°C for 2 minutes, which rose by 20°C/min until a temperature of 325°C was reached. This temperature was maintained for 3 minutes. The total run time was 16.24 minutes.

5.6.4. GC-MS analysis

All of the extracted lipid extracts were analysed by GC-MS using an Agilent 7890A Series chromatograph attached to a 5975 C Inert XL mass-selective detector with a quadropole mass analyser (Agilent Technologies, Cheadle, UK). Instrument conditions were identical to those reported elsewhere (Colonese *et al*. 2015; Craig *et al*. 2012). Briefly, a splitless injector was used and maintained at a temperature of 300°C. The carrier gas was helium, and the inlet/column head-pressure was constant. The GC column was inserted into the ion source of the MS. The ionisation energy of the MS was 70 eV and spectra were obtained by scanning between m/z 50 and 800. The majority of the samples (Åle, Bjørnsholm, Gamborg Fjord and Havnø) were run using a DB-5ms (5%-phenyl)-methylpolysiloxane column (30 m Å~ 0.250 mm Å~0.25 µm; method one). The temperature program for this

column was set at 50°C for 2 minutes, which rose by 10°C min^{-1} until a temperature of 325°C was reached. This temperature was maintained for 15 minutes. The total run time was 44.5 minutes. A second, longer column (DB23-ms, 50%-cyanopropyl)-methylpolysiloxane, 60 m Å~ 0.25 mm Å~ 0.25 μm; method two) was used for the samples that were recovered from Ronæs Skov, Teglgård-Helligkilde and Tybrind Vig. The temperature program for this column was set at 50°C for 2 minutes, which rose by 10°C min^{-1} for 5 minutes to 100°C, and then 4°C min^{-1} for 37.5 minutes until a temperature of 250°C was reached. This temperature was maintained for 20 minutes. The total run time was 64.5 minutes (Colonese *et al*. 2015).

5.6.5. Biomarker identification

The gas chromatograms of the lipid extracts, and the following biomarkers that were identified: range of saturated fatty acids (SFAs), dominant saturated fatty acid(s) (dom. SFA(s)), unsaturated fatty acids (UFAs), dicarboxilic fatty acids (DCFAs), alkyl phenolic fatty acids (APFAs), isoprenoid fatty acids (Isopre. FAs), cholesterol derivatives (chol. der.), triterpenoids (terp.), observation, short chain alkanes, and long chain alkanes, were tabulated. These were taken into consideration for the interpretation of vessel use.

Recently experimental analysis has established a number of criteria that should be met to confirm the presence of lipids of aquatic origin in archaeological ceramic vessels. Thus, the 'aquatic' class was based on the presence of ω-(o-alkylphenyl) alkanoic acids of carbon chain length $C_{18:0}$, $C_{20:0}$ and $C_{22:0}$, together with at the very least one of three isoprenoid fatty acids (Evershed *et al*. 2008). When dicarboxilic fatty acids of carbon chain length $C_{9:0}$ to $C_{13:0}$ or 3,7,11,25-tetramethylhexadecanoic acid (phytanic) as well as ω-(o-alkylphenyl) alkanoic acids of carbon chain length $C_{20:1}$ or $C_{22:1}$ were present, the identification to class was termed as a questionable 'aquatic' that was denoted by a question mark ('?'). If 3,7,11,25-tetramethylhexadecanoic acid (phytanic) or 2,6,10,14-tetramethylpentadecanoic acid (pristanic) isoprenoid fatty acids were present the identification to class was termed 'aquatic/ruminant', whereas when triterpenoids were identified the interpretation was termed 'plants'. Notably the presence of $C_{27:0}$ and $C_{29:0}$ was indicative of leafy wax.

While the interpretations were based on the presence of biomarkers, it is important to note that other foodstuffs may also have been processed in the vessels. Thus, the faunal assemblage as well as other material culture should be taken into consideration.

5.6.6. GC-C-IRMS analysis

Compound specific stable isotopic analysis of *n*-hexadecanoic ($\delta^{13}C_{16:0}$) and *n*-octadecanoic ($\delta^{13}C_{18:0}$) acids was undertaken on a sub-sample of the ceramic sherds, namely those extracts which yielded sufficient $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ fatty acids. Nine-extracted lipid samples were analysed using a gas chromatograph (Thermo Trace GC, Thermo Fisher Scientific, Bremen, Germany) connected to a combustion isotope ratio mass spectrometer (Thermo Delta V IRMS, Thermo Fisher Scientific, Bremen, Germany). The GC was fitted with a DB1-Mms (60 m 0.25 mm and 0.25 μm) column. The injector temperature was set at 50°C for 1 minute, then increased at 10°C per minute to 120°C. Finally the temperature was ramped to 250°C by 4°C per minute and an isothermal hold for 20 minutes. Helium (He) was used as the carrier gas, while the combustion reactor was set at 940°C (Craig *et al*. 2012; Heron *et al*. 2013). Anu Thompson of the University of Liverpool (UK) carried out the analysis. Instrument precision on repeated measurements was 0.2% (s.e.m.).

5.7. Results

5.7.1. Summary of samples analysed

5.7.1.1. Havnø

In total two food crusts and 22 sherds from the kitchen midden were selected for ORA. Unfortunately EA-IRMS could not be performed due to the lack of appreciable quantities of adhering food crusts. If lipids were present as evidenced by GC, GC-MS was performed on the samples to characterise the molecules and identify any product specific biomarkers. Since the initial run by GC, which was undertaken on 11 sherds, demonstrated that lipids were present in appreciable quantities, it was not considered worthwhile to analyse the remaining 13 sherds. Thus, all 24 samples were then analysed directly by GC-MS. A sub-sample of nine were analysed by GC-C-IRMS (Table 5.4 and 5.5). Overall, lipids were

preserved, and molecular signals that had absorbed into the vessel wall were identified.

Site	Sample type	Visible food crusts	Analysed by		
			EA-IRMS	GC and GC/MS	GC-C-IRMS
Åle	Ground ceramic	N	0	1	0
Bjørnsholm	Interior rim shard; interior body shard	N	0	2	0
Havnø	Food crust/sherd	Y	0	24	9
Gamborg Fjord	Food crust	Y	1	1	0
Teglgård-Helligkilde	Food crust/sherd	Y	1	1	0
Ronæs Skov	Food crust	Y	5	5	0
Tybrind Vig	Food crust/sherd	Y	1	2	0
Totals			**8**	**36**	**9**

Table 5.4: Summary of analyses performed on the samples per site.

5.7.1.2. Inter-site comparison

A summary of the different analyses performed on the sherds from the additional six sites is also listed in Tables 5.4 and 5.5. The one EBK sherd from Åle was analysed by GC and GC-MS. While GC was performed on the TRB sherds from Bjørnsholm, GC-MS analysis was only carried out on one of the samples. The adhering food crusts present on the six sherds recovered from Gamborg Fjord and Ronæs Skov were analysed by EA-IRMS, GC and GC-MS. The Teglgård-Helligkilde lamp was represented by two samples: one food crust that was analysed by EA-IRMS, and one ground ceramic sample that was analysed by GC and GC-MS. One of the two food crusts from Tybrind Vig was analysed by EA-IRMS and GC, whereas GC and GC-MS were performed on the second.

Site	Epoch	Description	Sample code	Sample type	EA-IRMS	GC	GC-MS	GC-C-IRMS
Åle	EBK	Unknown sherd	3251_RGH-2	Drilled ceramic (interior)	N	Y	Y	N
Bjørnsholm	TRB	Rim sherd	2911_UAR-A	Drilled ceramic (interior)	N	Y	Y	N
Bjørnsholm	TRB	Body sherd	2911_UAR-B	Drilled ceramic (interior)	N	Y	N	N
Gamborg Fjord	EBK	Body sherd (larger vessel)	A7154	Food crust	Y	Y	Y	N
Havnø	EBK	Large vessel	4014_DAO	Drilled ceramic (interior)	N	Y	Y	Y
Havnø	EBK	Medium sized vessel	4014_DGX	Drilled ceramic (interior)	N	Y	Y	Y
Havnø	EBK	Medium sized vessel	4014_FAF	Drilled ceramic (interior)	N	Y	Y	N
Havnø	EBK	Medium sized vessel	4014_FAJ	Drilled ceramic (interior)	N	Y	Y	Y
Havnø	EBK	Unknown sherd	4014_FBF	Drilled ceramic (interior)	N	Y	Y	N
Havnø	EBK	Small vessel	4014_HXZ	Drilled ceramic (interior)	N	Y	Y	Y
Havnø	EBK	Medium sized vessel	4014_PCE	Drilled ceramic (interior)	N	Y	Y	N
Havnø	EBK	Medium sized vessel	4014_SLG	Drilled ceramic (interior)	N	Y	Y	N
Havnø	EBK	Large vessel	4014_TBU	Drilled ceramic (interior)	N	Y	Y	N
Havnø	EBK	Medium sized vessel	4014_TEW	Drilled ceramic (interior)	N	Y	Y	Y
Havnø	EBK	Medium sized vessel	4014_TEW.I.R	Interior food crust	N	Y	Y	N
Havnø	TRB	Body sherd	4014_TU	Drilled ceramic (interior)	N	N	Y	Y
Havnø	TRB	Body sherd	4014_AQA	Drilled ceramic (interior)	N	N	Y	N

Site	Epoch	Description	Sample code	Sample type	EA-IRMS	GC	GC-MS	GC-C-IRMS
Havnø	TRB	Body sherd	4014_AQH	Drilled ceramic (interior)	N	N	Y	N
Havnø	TRB	Lower body sherd	4014_JQT	Drilled ceramic (interior)	N	N	Y	Y
Havnø	TRB	Neck sherd	4014_LMM	Drilled ceramic (interior)	N	N	Y	Y
Havnø	TRB	Neck sherd	4014_LMM.I.R	Interior food crust	N	N	Y	N
Havnø	TRB	Body sherd	4014_LUQ	Drilled ceramic (interior)	N	N	Y	Y
Havnø	TRB	Lower body sherd	4014_MDP	Drilled ceramic (interior)	N	N	Y	N
Havnø	TRB	Body sherd	4014_XXQ	Drilled ceramic (interior)	N	N	Y	N
Havnø	Unknown	Body sherd (larger, undecorated)	4014_ACAB-II	Drilled ceramic (interior)	N	N	Y	N
Havnø	Unknown	Unknown sherd (cf. neck)	4014_UOL	Drilled ceramic (interior)	N	N	Y	N
Havnø	Unknown	Drinking vessel (cf. neck sherd)	4014_AFCW-I	Drilled ceramic (interior)	N	N	Y	N
Havnø	Unknown	Rim sherd	4014_AFCW-II	Drilled ceramic (interior)	N	N	Y	N
Ronæs Skov	EBK	Body sherd (smaller vessel)	3705_ABE	Interior food crust	Y	Y	Y	N
Ronæs Skov	EBK	Body sherd	3705_AQQ	Food crust	Y	Y	Y	N
Ronæs Skov	EBK	Body sherd	3705_AFW	Interior food crust	Y	Y	Y	N
Ronæs Skov	EBK	Body sherd	3705_AWJ	Food crust	Y	Y	Y	N
Ronæs Skov	EBK	Body sherd	3705_AYU	Interior food crust	Y	Y	Y	N
Teglgård-Helligkilde	EBK	Lamp	TH1f (TH1-s)	Drilled ceramic (interior)	N	Y	Y	N

Site	Epoch	Description	Sample code	Sample type	EA-IRMS	GC	GC-MS	GC-C-IRMS
Teglgård-Helligkilde	EBK	Lamp	TH1f (TH1-f)	Interior food crust	Y	N	N	N
Tybrind Vig	EBK	Unknown sherd	2033_BQL.E.R	Exterior food crust	Y	Y	N	N
Tybrind Vig	EBK	Unknown sherd	2033_INT.I.R	Interior food crust	N	Y	Y	N

Table 5.5: Overview of the analyses performed on each sample.

5.7.2. EA-IRMS

Only two of the 22 sherds selected for ORA from Havnø had small quantities of adhering residues. Similarly, there was absence of food crusts on the ceramic sherds from the Åle and Bjørnsholm kitchen middens. The reasons for their low abundance and general absence at these types of site are probably attributable to the post depositional processes within kitchen middens or during the post excavation processing. In total, eight food crust samples adhering to the EBK vessels from Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde and Tybrind Vig were analysed by EA-IRMS. These data are plotted in Figure 5.14 and listed in Appendix 4.

In general, two distinguishable groups are represented: (1) Ronæs Skov (n = 1), Teglgård-Helligkilde (n = 1) and Tybrind Vig (n = 1), and (2) Gamborg Fjord (n = 1) and Ronæs Skov (n = 4). The sherd from Gamborg Fjord had a $\delta^{13}C$ value of -23.2‰ and 4.9‰ for $\delta^{15}N$, whereas the five sherds from Ronæs Skov had a mean $\delta^{13}C$ value of -23.3 + 1.2‰ and 5.8 ± 0.8‰ for $\delta^{15}N$. On the other hand the blubber lamp from Teglgård-Helligkilde had a $\delta^{13}C$ value of -18.8‰ and 15.6‰ for $\delta^{15}N$, and the sherd from Tybrind Vig had a $\delta^{13}C$ value of -22.6‰ and 12.3‰ for $\delta^{15}N$. The elevated $\delta^{15}N$ values of group one are consistent with those obtained from marine mussels reported by Craig *et al*. (2011), and the threshold of aquatic organisms (>8.0‰) suggested by Craig *et al*. (2007). Thus, these data probably represent a combination of different aquatic organisms, including marine mammals and piscivorous fish. In comparison the depleted $\delta^{15}N$ values of group two are consistent with those measured on acorn, einkorn wheat and milk reported by Craig *et al*.

(2011). The broad range in the $\delta^{15}N$ values (10.7‰) indicates that a number of different foodstuffs had been processed in the EBK vessels.

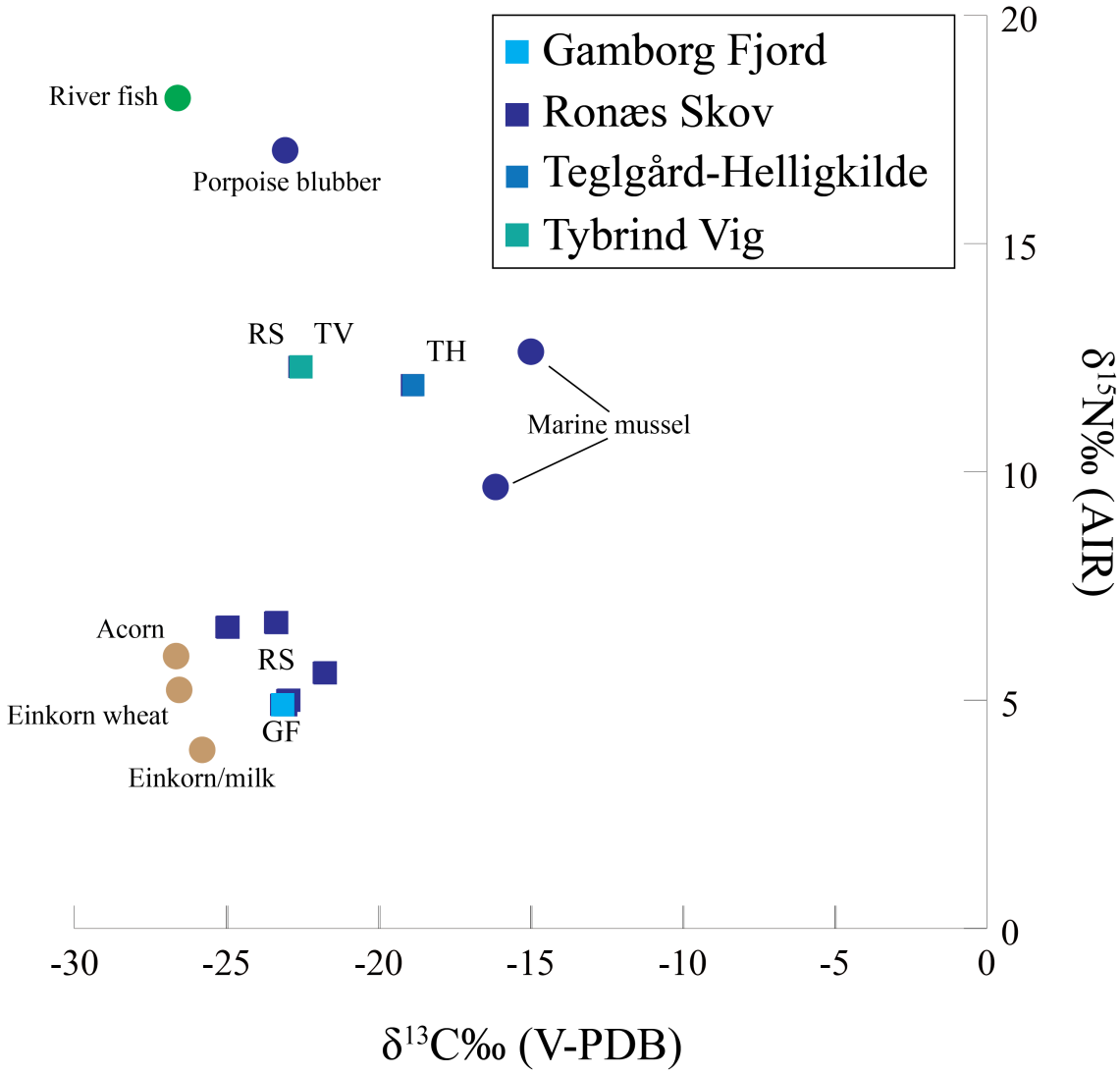


Figure 5.14: Bulk $\delta^{13}C$ and $\delta^{15}N$ stable isotope data of surface residues removed from the insides of eight EBK vessels recovered from coastal locations. Note the abbreviated sample locations. Modern reference samples are taken from Craig et al. (2011).

5.7.3. GC-FID

5.7.3.1. Havnø

In total, GC was performed on the 10 EBK sherds and one surface residue from the interior

of an EBK vessel (4014_TEW) recovered from the kitchen midden. The TRB and unknown sherds were not analysed limiting the potential for discussion. Of the 11 samples overall, the 10 sherds yielded data (Appendix 4). The overall lipid concentrations ranged from 6 to 80 $\mu g/g^{-1}$ (n = 10) producing a mean lipid concentration of 38.1 ± 22.9 $\mu g/g^{-1}$ (n = 10).

5.7.3.2. Inter-site comparison

Gas chromatography was performed on 11 of the 13 samples recovered from the other sampled sites (Åle, Bjørnsholm, Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde and Tybrind Vig). The ground ceramic sample of the Teglgård-Helligkilde lamp was analysed to the exclusion of the food crust. Similarly one of the two food crusts from Tybrind Vig was analysed. These data are listed in Appendix 4. The overall lipid concentrations for these samples ranged from 4 to 254 $\mu g/g^{-1}$ (n = 11).

Of the 38 samples selected for ORA, GC was performed on 22 samples. In total 20 contained lipids (91%) since a yield of <5 $\mu g/g^{-1}$ is considered uninterpretable due to the potential for contamination (Evershed 2008, 28). The summary statistics for each site included in this study are shown in Table 5.6. The overall lipid concentrations ranged from 4 to 254 $\mu g/g^{-1}$ (n = 21).

Site	**Sample description**	**Total lipid concentration ($\mu g/g^{-1}$)**	**Number of samples**
Åle	Drilled ceramic (interior)	19.2	1
Bjørnsholm	Drilled ceramic (interior)	16.1 ± 1.3	2
Gamborg Fjord	Food crust	254.0	1
Havnø	Drilled ceramic (interior)	38.1 ± 22.9	10
Ronæs Skov	Food crust	163.5 ± 74.2	5
Teglgård-Helligkilde	Drilled ceramic (interior)	56.2	1
Tybrind Vig	Exterior food crust	4.1	1

Table 5.6: Summary statistics for the sampled sites.

In general, the lipid concentrations from the ceramic vessels sampled from the kitchen middens was appreciably lower than those from the submerged localities. This is probably a reflection of the differences in the samples (food crusts versus ground ceramic) as well as the other post depositional processes at aerobic sites. The sherds recovered from the kitchen

middens had a mean lipid concentration of 33 ± 22 ($\mu g/g^{-1}$, n = 13), whereas those from the submerged localities had a mean of 141 ± 95 ($\mu g/g^{-1}$, n = 8).

Since the initial screen by GC showed that all of the samples analysed produced sufficient lipid concentrations (<5 $\mu g/g^{-1}$, Evershed 2008, 28), the remainder were ran directly by GC-MS.

5.7.4. GC-MS

5.7.4.1. Havnø

In total, 22 ceramic sherds and two food crusts from the kitchen midden were analysed by GC-MS to identify the biomarkers in the lipid extracts. The GC-MS demonstrated that saturated fatty acids with carbon lengths ranging from $C_{12:0}$ to $C_{28:0}$ were preserved in all 24 samples, whereas mono-unsaturated fatty acids with chain lengths of $C_{16:1}$, $C_{18:1}$, $C_{20:1}$, and $C_{22:1}$ were present in 23 samples. Unlike previous studies (Craig *et al*. 2011; Heron *et al*. 2013) there was a lack of $C_{24:1}$ and $C_{26:1}$ compounds, whereas polyunsaturated fatty acids ($C_{20:2}$) were preserved in only one sample. Dicarboxilic fatty acids (hereafter diacids) with carbon lengths ranging from $C_{9:0}$ to $C_{26:0}$ were preserved in 11 samples. Isoprenoid fatty acids 3,7,11,25-tetramethylhexadecanoic acid (phytanic) and 2,6,10,14-tetramethylpentadecanoic acid (pristanic) were preserved in six samples, whereas long chain alkanes with carbon lengths of $C_{27:0}$ and $C_{29:0}$ were present in 11 samples. Ketones (C31 and C35) were preserved in a total of three samples. Although cholesterol, which is an indicator of animal fat, and triterpenoids that are a generic class of natural products (Pollard and Heron 2008) were not identified in any of the 24 samples, degradation should be taken into consideration as well as the possibility that they may have been removed during the acid extraction. Moreover, solvent extraction may have yielded different data had it been used. Since it is a relatively novel method (Correa-Ascencio and Evershed 2014) it was subsequently applied on the samples from the other sampled sites. While the following interpretations were based on the presence of specific lipid biomarkers (Table 5.7), it is important to note that other foodstuffs may also have been processed in the vessels.

Despite the presence of long-chain unsaturated fatty acids (>$C_{18:1}$) that are commonly concentrated in the tissues of aquatic taxa (Heron *et al*. 2013), these data are not sufficient enough to confirm that aquatic products were processed in the 24 samples since they naturally occur in a wide variety of products. In total, ω-(o-alkylphenyl) alkanoic acids with a carbon chain length of $C_{18:0}$ were present in three samples (EBK, n = 1, TRB, n = 2). These stable compounds are formed when unsaturated fatty acids or tri-, di- or monounsaturated fatty acids are subjected to prolonged (at least 17 hours) temperatures (>270°C), they widely occur within fats and oils of marine and terrestrial origin (Copley *et al*. 2004; Evershed *et al*. 2008; Hansel *et al*. 2004). The $C_{18:0}$ ω-(o-alkylphenyl) alkanoic acids as detected here are derived from polyunsaturated $C_{18:0}$ precursors that are present in aquatic as well as plant oils. Unfortunately the $C_{20:0}$ component that is diagnostic of aquatic products was not identified (Hansel *et al*. 2004). However, the presence of at least one (phytanic) of three isoprenoid fatty acids alongside the ω-(o-alkylphenyl) alkanoic acids in two TRB sherds is highly indicative of degraded aquatic oils within archaeology (Evershed *et al*. 2008).

In addition, isoprenoid fatty acids, including phytanic acid (3,7,11,25-tetramethylhexadecanoic), and pristanic acid (2,6,10,14-tetramethylpentadecanoic) were present in four TRB sherds. Although isoprenoid fatty acids widely occur in marine organisms, they are found in very low concentrations in animals of terrestrial origin (Ackman and Hooper 1968; Copley *et al*. 2004). Thus, these data are not sufficient on their own to confirm that aquatic products were processed in these funnel beakers.

Diacids with carbon lengths ranging from $C_{9:0}$-$C_{26:0}$ were identified in five EBK and six TRB sherds. Diacids are known to arise from the oxidation of monounsaturated and polyunsaturated fatty acids (Passi *et al*. 1993; Regert *et al*. 1998), and have been characterized in aquatic resources (Bell and Tocher 2009), the ORA of smoke from several wood species (Fine *et al*. 2001, 2002; Simoneit 2002), nuts (Dembitsky *et al*. 2002), and wood bark (Loveland and Laver 1972; Santos Bento *et al*. 2001).

Sample code	SFAs	dom. SFA(s)	UFAs	DCFAs	APFAs	Isopre. FAs	LCAs	K	int.
4014_DAO	C14-C28	C16; C18	C18:1; C20:1; C22:1	C9-C13	C18		C27; C29		Plant
4014_DGX	C12-C28	C16; C18	C16:1; C18:1				C27; C29		Plant
4014_FAF	C14-C26	C16; C18	C16:1; C18:1				C27; C29		Plant
4014_FAJ	C14-C28	C14; C16; C18	C16:1; C18:1	C9			C27; C29		Plant/ ruminant
4014_FBF	C12-C28	C15; C16; C18	C16:1; C18:1; C20:1	C14-C26					Plant
4014_HXZ	C14-C28	C16; C18	C16:1; C18:1; C20:1; C22:1				C27; C29		Plant
4014_PCE	C12-C26	C16; C18	C16:1; C18:1; C22:1	C9-C13			C27; C29		Plant
4014_SLG	C12-C28	C16; C18	C16:1; C18:1; C20:1; C22:1				C27; C29		Plant
4014_TBU	C14-C28	C16; C18	C16:1; C18:1						
4014_TEW	C14-C28	C16; C18	C16:1; C18:1	C9			C27; C29		Plant
4014_TEW.I.R	C16-C18								
4014_TU	C14-C24	C16; C18	C16:1; C18:1; C20:1	C9-C13	C18	Phytanic			Aquatic or ruminant
4014_AQA	C14-C28	C16; C18	C16:1; C18:1; C20:1; C22:1	C9-C17	C18	Phytanic			Aquatic (?)
4014_AQH	C12-C28	C16; C18	C16:1; C18:1; C20:1	C9-C15			C27; C29		Plant
4014_JQT	C12-C28	C16; C18	C16:1; C18:1; C20:1; C22:1	C9-C22		Phytanic; pristanic		C31; C35	Aquatic/ plant or ruminant
4014_LMM.I.R	C16-C18	C18	C18:1						

Sample code	SFAs	dom. SFA(s)	UFAs	DCFAs	APFAs	Isopre. FAs	LCAs	K	int.
4014_LMM	C14-C24	C16; C18	C16:1; C18:1; C20:1; C22:1	C9-C17		Phytanic		C31; C35	Aquatic or ruminant
4014_LUQ	C14-C26	C16; C18	C18:1; C20:1			Phytanic		C31; C35	Aquatic or ruminant
4014_MDP	C16-C28	C16; C18	C16:1; C18:1				C27; C29		Plant
4014_XXQ	C14-C28	C16; C18	C16:1; C18:1; C20:1; C22:1	C9-C13		Phytanic	C29		Aquatic/ plant or ruminant
4014_ACAB-II	C16-C28	C16; C18	C16:1; C18:1; C20:1; C20:2; C22:1						
4014_UOL	C16-C24	C16; C18	C16:1; C18:1; C20:1; C22:1						
4014_AFCW-I	C14-C26	C16; C18	C16:1; C18:1						
4014_AFCW-II	C16-C26	C16; C18	C16:1; C18:1; C20:1; C22:1						

Table 5.7: Havnø molecular results: GC-MS. Range of saturated fatty acids (SFAs), dominant saturated fatty acid(s) (dom. SFA(s)), unsaturated fatty acids (UFAs), dicarboxilic fatty acids (DCFAs), alkyl phenolic fatty acids (APFAs), isoprenoid fatty acids (Isopre. FAs), long chain alkanes (LCAs), and ketones (K) were tabulated. The aforementioned were taken into consideration for the interpretation (int.) of vessel use. Sample and vessel descriptions are provided in Table 5.5.

The presence of the long chain alkanes, including carbon chains of $C_{27:0}$ and $C_{29:0}$ that were identified in eight EBK and three TRB vessels are consistent with, but not diagnostic of, plant products. In addition, ketones (C31 and C35) that are the by-products of triglycerides and consistent with the epicuticular waxes of higher plants (Charters *et al*. 1995; Walton 1990) as well as animal fats (Raven *et al*. 1997) were present in three TRB vessels. Their presence indicates that heating at high temperatures (Evershed 2008; Evershed *et al*. 1995) took place.

It is highly unlikely that the absorbed residue's constituents are derived from post-depositional contamination because of the presence of ω-(o-alkylphenyl)alkanoic acids and ketones that can only be formed by heating (Hansel *et al*. 2004; Raven *et al*. 1997). Figures 5.15 and 5.16 show an EBK pointed based vessel, and a TRB funnel beaker that exhibited possible degraded aquatic oils. The major fatty acids (Cn:x) with carbon length (n), and number of unsaturations (x), and the internal standard (IS, n-hexatriacontane) are provided in the partial gas chromatograph (above figure). The extracted ion chromatograph reporting m/z 105 of the same sample is also provided (underneath figure), and shows the range of ω-(o-alkylphenyl)alkanoic acids with carbon atoms of 18 (filled circles). Total ion chromatograms can be found for all samples in Appendix 4.

The GC-MS demonstrated that a combination of different resources had been processed in the vessels recovered from the kitchen midden (Table 5.8). Based on these data alone the EBK vessels appeared to have had restricted uses when compared to the TRB funnel beakers. None of the samples had unequivocal evidence to suggest that products of aquatic origin had been processed due to the absence of $C_{20:0}$. The presence of $C_{18:0}$ is highly indicative although it is difficult to interpret since it was, in general, highly degraded. To clarify further GC-C-IRMS was performed on five pointed based vessels and four funnel beakers from the kitchen midden. This analysis yielded different data that will be discussed below.

Site	**Lipid class**	**EBK**	**TRB**	**Totals**
Havnø	Aquatic (?)		1	**1**
	Aquatic/plant or ruminant		2	**2**
	Aquatic or ruminant		3	**3**
	Plant/ruminant	9	2	**11**
Totals		**9**	**8**	**17**

Table 5.8: Main classes of lipids identified in the ceramic vessels from Havnø. The identified lipid biomarkers were used to identify the marine derived products (Craig et al. 2011; Hansel et al. 2004; Saul et al. 2014).

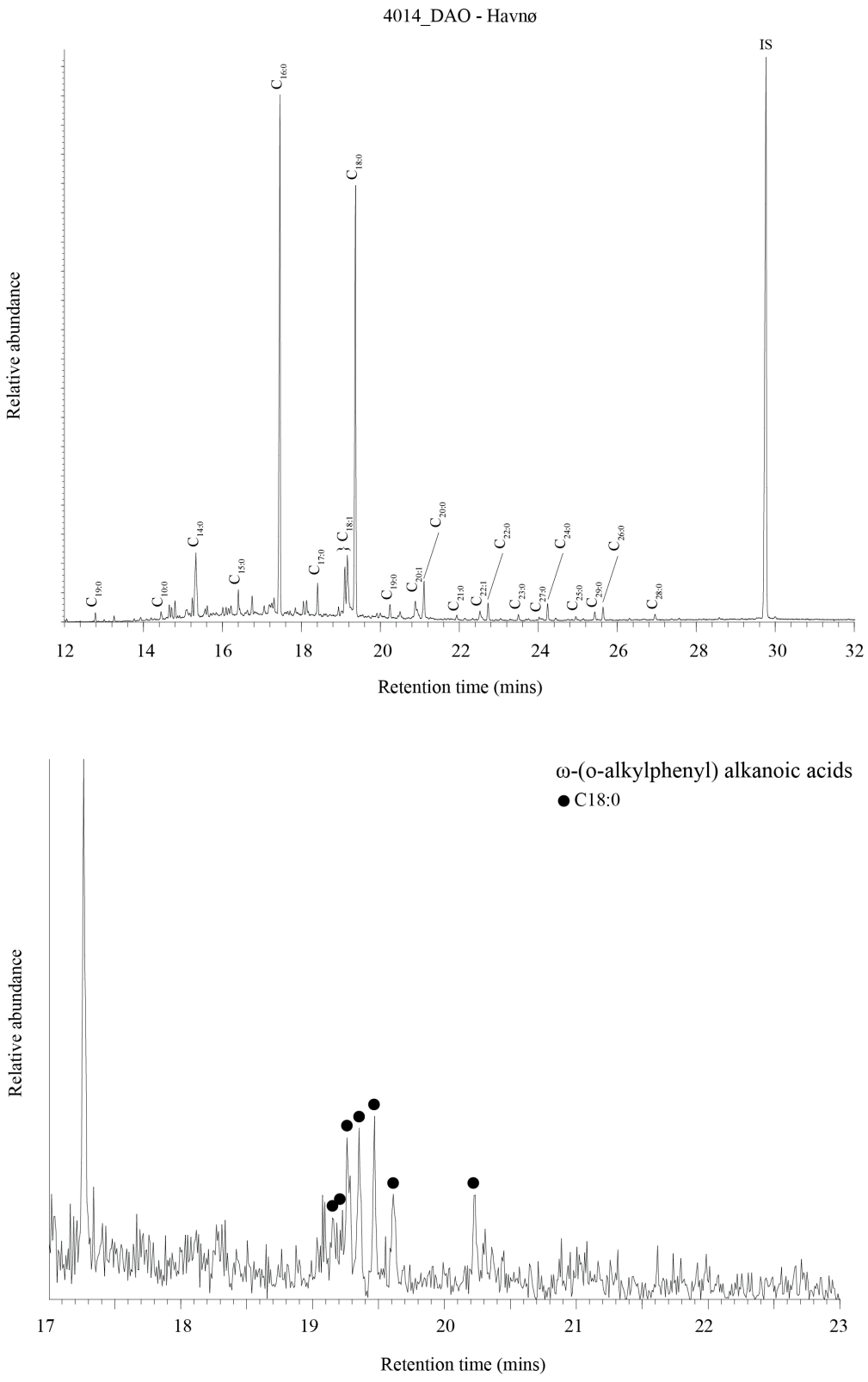


Figure 5.15: Partial gas chromatograph (above figure), and extracted ion chromatograph reporting m/z 105 of an EBK sherd (DAO) recovered from Havnø. Note that only the FAs are labelled.

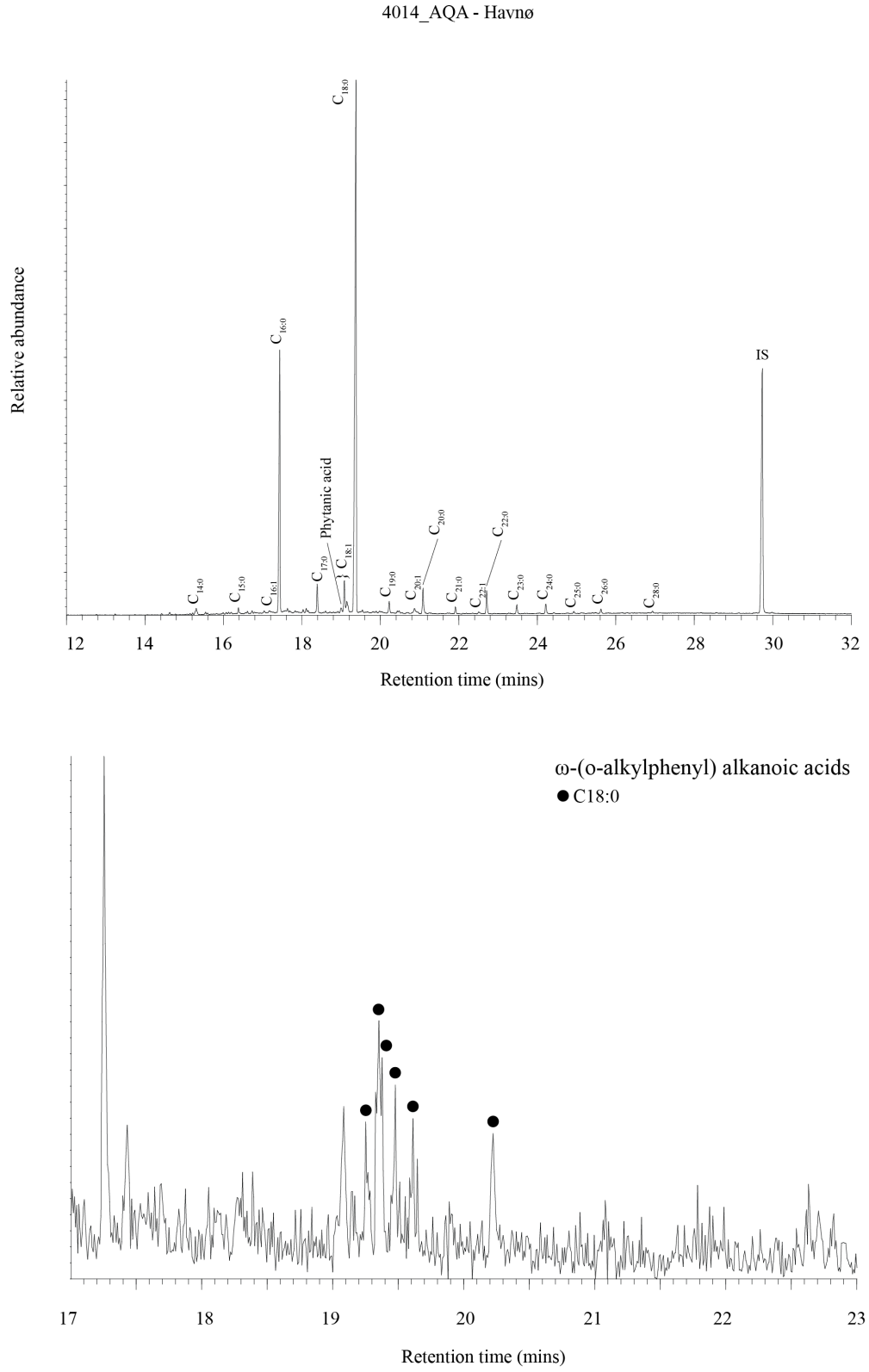


Figure 5.16: Partial gas chromatograph (above figure), and extracted ion chromatograph reporting m/z 105 of a TRB sherd (AQA) recovered from Havnø. Note that only the FAs are labelled.

5.7.4.2. Inter-site comparison

For comparison, three ceramic sherds from Åle, Bjørnsholm and Teglgård-Helligkilde as well as seven food crusts adhering to vessels recovered from Gamborg Fjord, Ronæs Skov, and Tybrind Vig were analysed by GC-MS to identify the biomarkers in the lipid extracts. The GC-MS demonstrated that saturated fatty acids with carbon lengths ranging from $C_{12:0}$ to $C_{28:0}$ and mono-unsaturated fatty acids with chain lengths of $C_{16:1}$, $C_{18:1}$, $C_{20:1}$, and $C_{22:1}$ were preserved in all 10 samples. Similarly there was an absence of carbon chains up to $C_{24:1}$ and $C_{26:1}$, whereas polyunsaturated fatty acids ($C_{20:2}$) were present in three food crusts from Ronæs Skov. Diacids with carbon lengths ranging from $C_{9:0}$ to $C_{13:0}$ were preserved in two food crust samples (Teglgård-Helligkilde and Tybrind Vig), while ω-(o-alkylphenyl) alkanoic acids with carbon lengths of $C_{16:0}$, $C_{18:0}$ and $C_{20:0}$ were present in nine samples. Isoprenoid fatty acids 3,7,11,25-tetramethylhexadecanoic acid (phytanic) and 2,6,10,14-tetramethylpentadecanoic acid (pristanic) were preserved in five samples, whereas 4,8,12-trimethyltridecanoic acid (4,8,12-TMTD) was present in six samples. Long chain alkanes with carbon lengths of $C_{27:0}$, $C_{29:0}$, $C_{33:0}$ and $C_{35:0}$ were present in three samples, whereas ketones (C31) were preserved in only one sample. Similarly there was a lack of cholesterol, although triterpenoids were preserved in six food crusts sampled. These data are listed in Table 5.9.

In a similar manner to the Havnø ceramic vessels, long-chain unsaturated fatty acids ($>C_{18:1}$) were present in all 10 samples. Similarly, these data were not sufficient enough to confirm that aquatic products were processed in these vessels (Heron *et al*. 2013). Likewise, nine of the samples (EBK, $n = 8$; TRB, $n = 1$) also contained aquatic biomarkers, notably ω-(o-alkylphenyl) alkanoic acids. Of these, isoprenoid fatty acids, including phytanic acid (3,7,11,25-tetramethylhexadecanoic), pristanic acid (2,6,10,14-tetramethylpentadecanoic), and 4,8,12-trimethyltridecanoic acid (4,8,12-TMTD) were preserved in six samples. Thus, the presence of ω-(o-alkylphenyl) alkanoic acids and isoprenoid fatty acids met the established criteria (Evershed *et al*. 2008), and demonstrated that products of aquatic origin had been processed in the EBK vessels from Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde, and Tybrind Vig, as well as a funnel beaker from the Bjørnsholm kitchen midden.

Site (sample code)	SFAs	dom. SFA(s)	UFAs	DCFAs	APFAs	Isopre. FAs	Terp.	LCAs	int.
Åle (RGH-2)	C14-C26	C16; C18	C18:1					C27; C29	Plant
Bjørnsholm (UAR-A)	C12-C26	C16	C18:1		C18	Pristanic; TMTD			Aquatic (?)
Bjørnsholm (UAR-B)	Did not run								
Gamborg Fjord (A7154)	C14-C28	C16	C18:1		C18; C20	TMTD	P		Aquatic
Ronæs Skov (ABE)	C14-C26	C16; C18	C16:1; C18:1; C20:1; C20:2; C22:1		C18; C20	Phytanic; pristanic; TMTD	P		Aquatic
Ronæs Skov (AQQ)	C14-C28	C16; C18; long chain FA	C16:1; C18:1; C20:1; C20:2; C22:1		C18		P	C27; C29; C33; C35; odd chain alkanes	Aquatic (?)/Plant

Site (sample code)	SFAs	dom. SFA(s)	UFAs	DCFAs	APFAs	Isopre. FAs	Terp.	LCAs	int.
Ronæs Skov (AFW)	C14-C26	C16; C18	C16:1; C18:1; C20:1; C22:1		C18		P		Aquatic (?)
Ronæs Skov (AWJ)	C14-C28	C16; C18	C16:1; C18:1; C20:1		C18		P		Aquatic (?)
Ronæs Skov (AYU)	C16-C26	C16; C18	C16:1; C18:1; C20:1; C22:1		C18	Phytanic; TMTD	P		Aquatic (?)
Teglgård-Helligkilde (1f (1-f))	C14-C24	C16; C18	C16:1; C18:1; C20:2	C9-C13	C18; C20	Phytanic; pristanic; TMTD			Aquatic
Teglgård-Helligkilde (1f (1-s))	Did not run								
Tybrind Vig (BQL.E.R)	Did not run								

Site (sample code)	SFAs	dom. SFA(s)	UFAs	DCF As	APFAs	Isopre. FAs	Terp.	LCAs	int.
Tybrind Vig (INT.I.R)	C14-C24	C16; C18	C16:1; C18:1; C20:1	C9-C12	C16; C18; C20	Phytanic; TMTD		C27; C29	Aquatic/ plant

Table 5.9: Inter-site molecular results: GC-MS. Range of saturated fatty acids (SFAs), dominant saturated fatty acid(s) (dom. SFA(s)), unsaturated fatty acids (UFAs), dicarboxilic fatty acids (DCFAs), alkyl phenolic fatty acids (APFAs), isoprenoid fatty acids (Isopre. FAs), triterpenoids (terp. (P denotes presence)), and long chain alkanes (LCAs), were tabulated. The aforementioned were taken into consideration for the interpretation (int.) of vessel use. Sample and vessel descriptions are provided in Table 5.5.

Figure 5.17 shows a typical adhering food crust exhibiting degraded aquatic oils. The major fatty acids (Cn:x) with carbon length (n), and number of unsaturations (x), and the internal standard (IS, n-hexatriacontane) are provided in the partial gas chromatograph (above figure). The extracted ion chromatograph reporting m/z 105 of the same sample (INT.I.R.) is also provided (underneath figure), and shows the range of ω-(o-alkylphenyl)alkanoic acids with carbon atoms of 16 (open circles), 18 (filled circles), and 20 (open squares).

Diacids with carbon lengths ranging from $C_{9:0}$-$C_{13:0}$ were identified in two samples, namely the EBK lamp from Teglgård-Helligkilde, and the interior food crust from a pointed based vessel recovered from Tybrind Vig. These data demonstrate that aquatic products had probably been processed. Long chain alkanes, including carbon chains of $C_{27:0}$, $C_{29:0}$, $C_{33:0}$ and $C_{35:0}$ were preserved in the one funnel beaker from Bjørnsholm as well as two EBK vessels (Ronæs Skov and Tybrind Vig). In addition, the presence of ketones (C31) in one pointed based vessel from Ronæs Skov demonstrated that leafy vegetables or animal fats (Evershed 2008; Raven *et al*. 1997) had been processed. Furthermore, triterpenoids that is a generic class of natural products (Pollard and Heron 2008) were preserved the six food crusts adhering to the EBK vessels recovered from Gamborg Fjord and Ronæs Skov, and reinforce the notion that different fauna and flora were processed during the late Mesolithic.

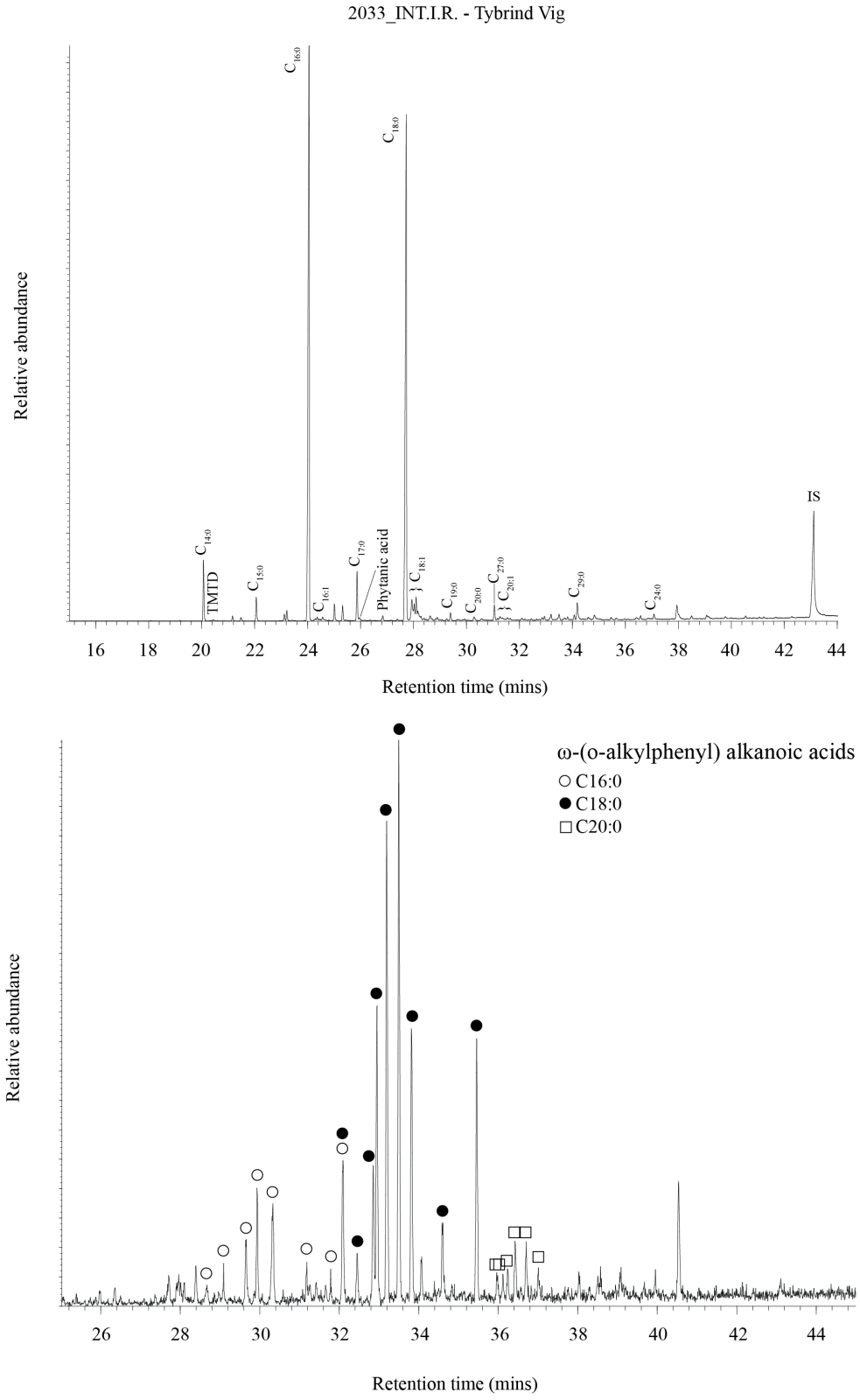


Figure 5.17: Partial gas chromatograph (above figure), and extracted ion chromatograph reporting m/z 105 of lipid extracts from an EBK vessel recovered from Tybrind Vig. Only the FAs are labelled.

On the whole GC-MS demonstrated that while a combination of resources were processed at the six sites the variability was not as pronounced when compared with Havnø (Table 5.10). Despite the limitations of GC-MS, based on these data alone, the EBK vessels (*n* = 9) were primarily used for the processing of aquatic and plant products, whereas the lipid extracts from the one funnel beaker recovered from Bjørnsholm demonstrated that aquatic resources continued to be processed after the introduction of domesticated fauna and flora.

Site	**Lipid class**	**EBK**	**TRB**	**Totals**
Åle	Plant	1		1
Bjørnsholm	Aquatic (?)		1	1
Gamborg Fjord	Aquatic	1		1
Ronæs Skov	Aquatic	1		1
	Aquatic (?)	3		3
	Aquatic (?)/Plant	1		1
Teglgård-Helligkilde	Aquatic	1		1
Tybrind Vig	Aquatic/plant	1		1
Totals		9	1	10

Table 5.10: Main classes of lipids identified in the ceramic vessels from the other sampled sites. The identified lipid biomarkers were used to identify the marine derived products (Craig et al. 2011; Hansel et al. 2004; Saul et al. 2014).

5.7.5. GC-C-IRMS

Compound specific stable isotopic analysis of *n*-hexadecanoic ($\delta^{13}C_{16:0}$) and *n*-octadecanoic ($\delta^{13}C_{18:0}$) acids was undertaken on a sub-sample of the ceramic sherds from Havnø. Overall, those lipid extracts that yielded sufficient quantities of $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ fatty acids were selected for GC-C-IRMS. In total five EBK and four TRB vessels were analysed. These data are plotted in Figure 5.18 and listed in Appendix 4.

The $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ for all sampled sherds ranged from -30.0 to -24.4‰, and -32.6 to -25.7‰ respectively, with a clear distinction between the EBK and TRB vessels (Figure 5.18). The $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ of the EBK vessels ranged from -30.0 to -24.4‰, and -29.6 to -25.7‰, whereas those from the subsequent TRB ranged from -29.0 to -27.8‰, and -32.6 to -29.8‰.

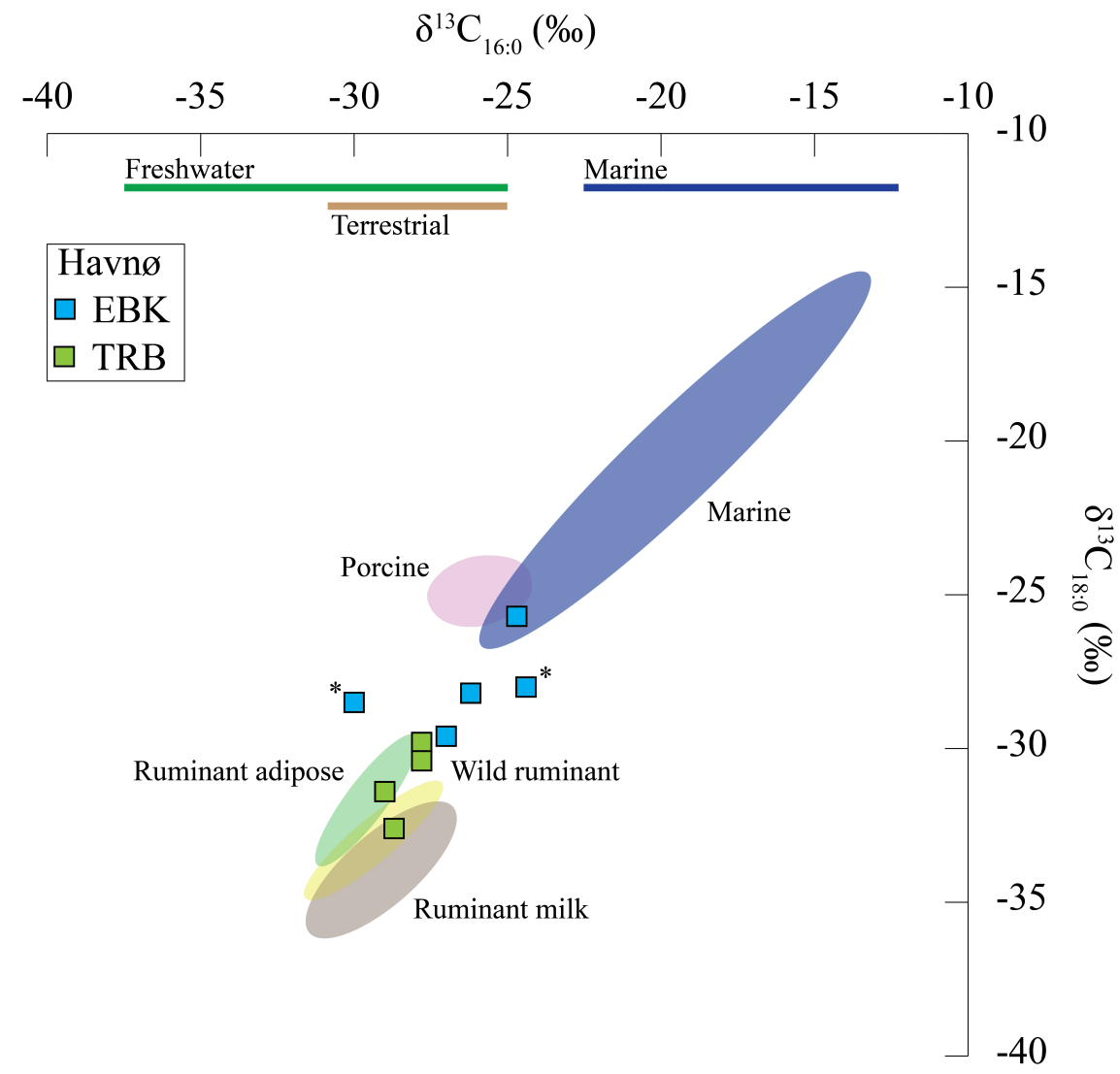


Figure 5.18: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from EBK (n = 5) and TRB (n = 4) vessels from the Havnø kitchen midden. The samples that yielded aquatic biomarkers are marked with an asterisk. The ellipses of northern European authentic reference fats are described above (Dudd and Evershed 1998; Craig et al. 2011, 2013).

On the whole the EBK vessels did not plot within the ellipses established from a number of $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ obtained from northern European taxa (Craig *et al*. 2011, 2013; Dudd and Evershed 1998). These data indicate that a combination of resources, including aquatic (freshwater and marine) and terrestrial products had been processed in the vessels. However, sherd DGX (EBK) that had a $\delta^{13}C_{16:0}$ value of -24.7 and -25.7‰ for $\delta^{13}C_{18:0}$ plotted within the ellipse established for marine organisms. On the other hand the

TRB vessels plotted within the ellipses established for ruminants, including dairy. It can be seen that there was a temporal change in vessel use across the Mesolithic-Neolithic transition at Havnø.

5.8. Discussion

5.8.1. Culinary change at Havnø

The analyses confirmed that lipids were preserved in the ceramic vessels recovered from the Havnø kitchen midden. The lipid extracts probably reflect the long-term use of the vessels since they had absorbed into the vessel walls as opposed to adhering food crusts. In addition, molecular signals were preserved that could be identified. Gas chromatography-mass spectrometry demonstrated that a combination of products had been processed in both the pointed based vessels of the EBK and the TRB funnel beakers. The presence of ω-(o-alkylphenyl) alkanoic acids and isoprenoid fatty acids in seven different vessels is consistent with aquatic resources but not absolute. This is due to the lack of $C_{20:0}$ and the fact that they did not meet the strict criteria (Evershed 2008). To explore further, GC-C-IRMS was performed on a sub sample of nine sherds. These data demonstrated that the EBK ceramic vessels were used to process a combination of aquatic and ruminant resources, whereas the TRB funnel beakers were solely used to process ruminant foodstuffs including dairy. These data indicated that a change in the use of the ceramic vessels took place at the kitchen midden (Table 5.11). Interestingly Havnø differed somewhat to the other Danish localities sampled as well as the comprehensive analysis undertaken from material from southern Scandinavia (Craig *et al*. 2007, 2011; Heron *et al*. 2007, 2013, 2015).

5.8.2. Inter-site comparison

For inter-site comparison a number of ceramic sherds and food crusts were sampled: Åle, Bjørnsholm, Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde, and Tybrind Vig. In addition, previous ORA on 64 absorbed lipids and carbonised food crusts from 13 sites have been made available (Craig and Heron unpublished data). In the following section these data as well as previously published ORA on Danish material will be summarised.

Site	Lipid class	EBK	TRB	Totals
Havnø	Aquatic	1		**1**
	Aquatic (?)		1	**1**
	Aquatic/plant/ruminant	8	3	**11**
	Ruminant		4	**4**
Totals		**9**	**8**	**17**

Table 5.11: Main classes of lipids identified in the ceramic vessels from Havnø. The primary criteria for assignation to class were based on the GC-C-IRMS data. When combinations of lipids were reported, the dominant lipid class is reported. If there was an absence of GC-C-IRMS data the lipid biomarkers from GC-MS were used.

5.8.3. EA-IRMS

In this study eight food crust samples adhering to EBK vessels from Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde and Tybrind Vig were analysed by EA-IRMS. Figure 5.19 plots these data alongside previously published (Øgårde kar S, Teglgård-Helligkilde and Tybrind Vig) and unpublished (Åkonge, Roskilde Fjord, Salpetermosen and Stenø) $\delta^{13}C$ and $\delta^{15}N$ values (n = 50). All available data, regardless of whether only bulk carbon isotope values are reported are listed in Appendix 4.

In total, 54 vessels from 10 Danish localities have been previously sampled, however, for some (n = 4) only the carbon stable isotope values are reported (Appendix 4). Despite the absence of data from coastal localities dating to the TRB, four obvious groups are represented (Figure 5.20). Group one is represented by EBK (n = 1) and TRB (n = 6) food crusts adhering to ceramic vessels recovered from inland localities. These food crusts had a mean $\delta^{13}C$ value of -27.2 ± 0.3‰ and 11.1 ± 0.6‰ for $\delta^{15}N$. On the other hand, group two represented by two surface residues adhering to a pointed based vessel and a lamp (Teglgård-Helligkilde and Tybrind Vig) had a mean $\delta^{13}C$ value of -20.7 ± 2.7‰ and 14.0 ± 2.3‰ for $\delta^{15}N$. Group three comprised of 14 EBK and 14 TRB food crusts adhering to ceramic vessels recovered from inland localities. These samples had a mean $\delta^{13}C$ value of -28.0 ± 1.0‰ and 7.6 ± 1.1‰ for $\delta^{15}N$. Group four included the food crusts adhering to 13 EBK vessels recovered from coastal localities as well as one surface residue on a funnel beaker recovered from the inland site at Åkonge. These samples had a mean $\delta^{13}C$ value of -22.8 ± 1.5‰ and 6.8 ± 1.6‰ for $\delta^{15}N$ (Craig *et al*. 2007, 2011; Heron *et al*. 2013).

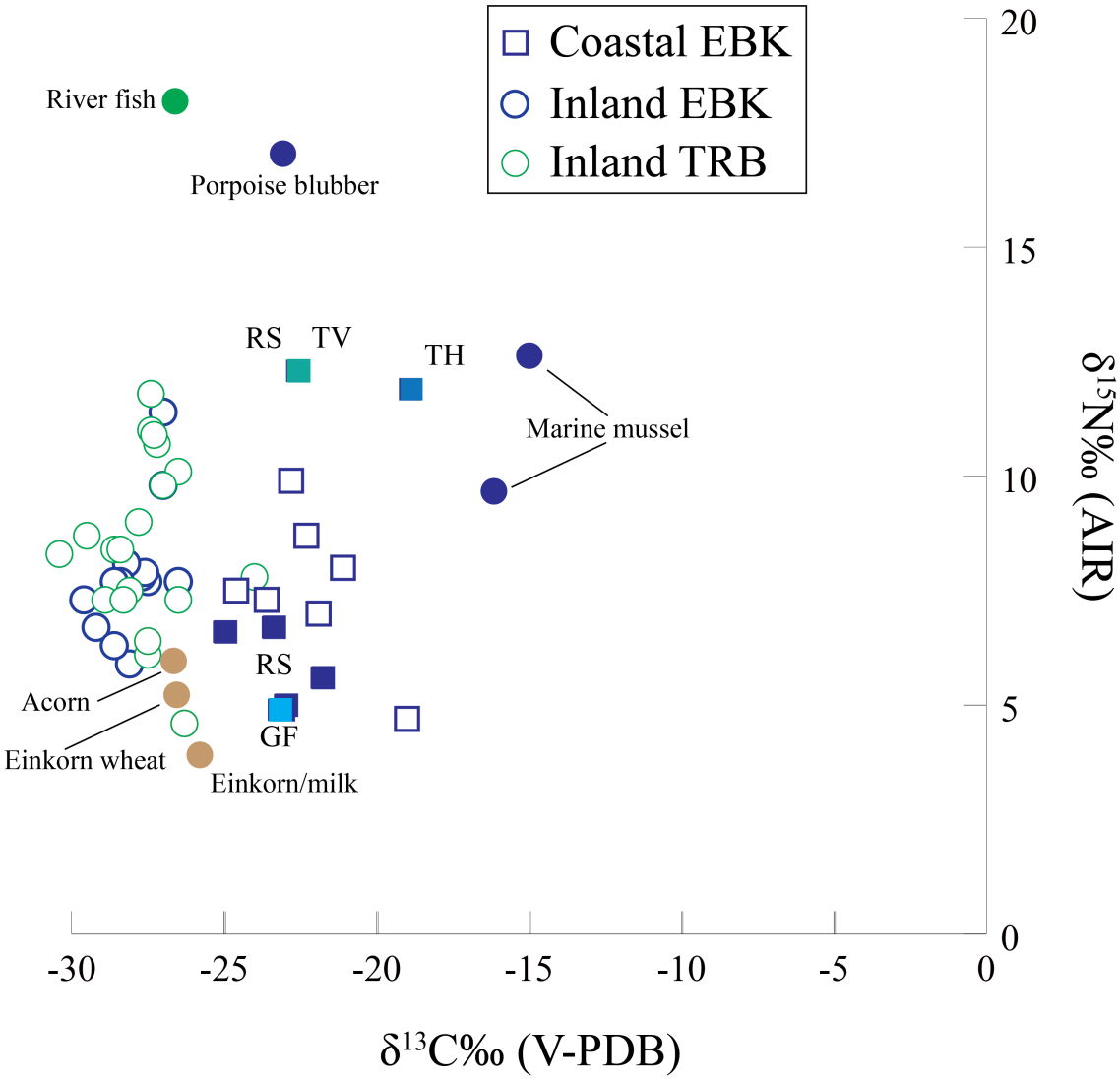


Figure 5.19: Bulk stable $\delta^{13}C$ and $\delta^{15}N$ isotope data of surface residues analysed in this study compared with EBK coastal (n = 7), EBK inland (n = 15), and TRB inland (n = 20) samples (Craig and Heron unpublished; Craig et al. 2007, 2011; Heron et al. 2013). Note that there is an absence of data from coastal TRB sites. Gamborg Fjord (GF), Ronæs Skov (RS), Teglgård-Helligkilde (TH), and Tybrind Vig (TV).

Group one had a narrow range in their $\delta^{15}N$ values (1.7‰) indicating that aquatic organisms of freshwater origin had probably been processed in these vessels. Similarly, the elevated $\delta^{15}N$ values of group two are consistent with those obtained from marine mussels reported by Craig *et al*. (2011), and the threshold of aquatic organisms (>8.0‰) suggested by Craig *et al*. (2007). Thus, group two probably represent a combination of different aquatic organisms, including marine mammals and piscivorous fish. In comparison, the

broad range in the $\delta^{15}N$ values (4.6‰) of group three indicate that a number of resources at different trophic level hierarchies had been processed. Given the threshold, at least eight of these vessels had been used for the processing of aquatic organisms of freshwater origin. On the other hand, the remainder (n = 20) had been used to process ruminants and plant products vessels especially when the restricted range in their $\delta^{13}C$ values (4.1‰) are taken into consideration. In comparison with group two, the depleted $\delta^{15}N$ values of group four probably represent a mixture of different foodstuffs, including aquatic organisms, for instance piscivorous fish and shellfish, and terrestrial foodstuffs, including ruminants.

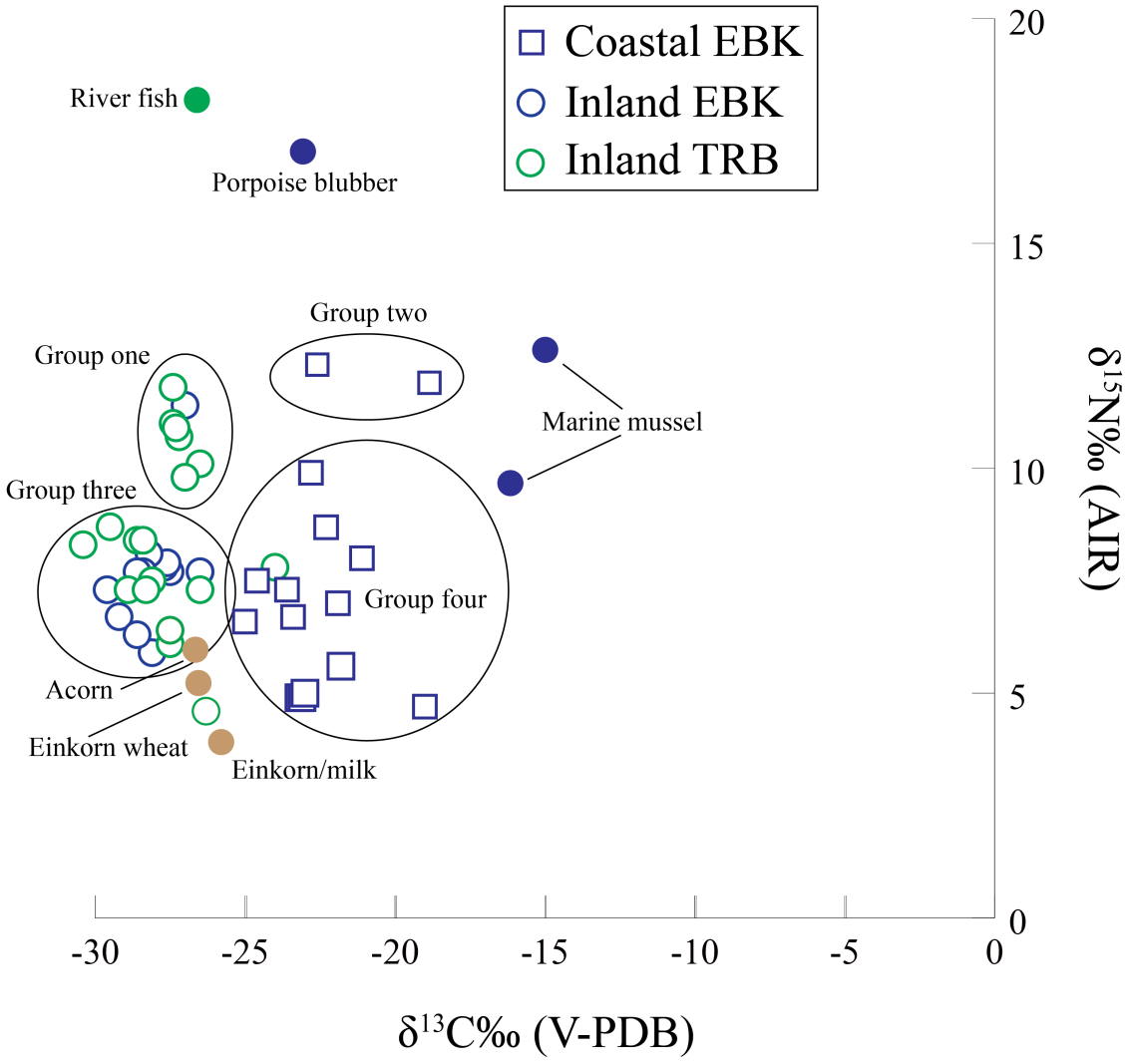


Figure 5.20: Bulk stable $\delta^{13}C$ and $\delta^{15}N$ isotope data of 50 surface residues from 10 Danish localities that have been grouped (Craig and Heron unpublished; Craig et al. 2007, 2011; Heron et al. 2013). Note that there is an absence of data from coastal TRB sites.

5.8.4. GC-MS

Despite the comprehensive ORA from material recovered from southern Scandinavian, the data derived from GC-MS is restricted to only 28 Danish samples (Appendix 4). In comparison with the analysis undertaken in this study, saturated fatty acids with carbon lengths ranging from $C_{6:0}$ to $C_{32:0}$ are reported for only four samples, whereas mono-unsaturated fatty acids with chain lengths of $C_{14:1}$ to $C_{24:1}$ were similarly present in four samples. In addition, polyunsaturated fatty acids ($C_{18:2}$ to $C_{20:2}$) were identified in three samples. In contrast with the present study, isoprenoid fatty acids, including phytanic and TMTD, were preserved in 17 samples whereas ω-(o-alkylphenyl) alkanoic acids with carbon lengths of $C_{16:0}$, $C_{18:0}$, $C_{20:0}$ and $C_{22:0}$ were present in 10 samples. Furthermore, precursor $C_{16:3}$, $C_{18:3}$ and $C_{20:3}$ fatty acyl components were present in 20 samples (Hansel *et al*. 2004). While the latter are common constituents of marine and vegetable oils, the $C_{20:3}$ component is only observed in the former (Passi *et al*. 2002). On the whole, these data demonstrated to the authors that aquatic resources were processed in the majority of these vessels (Craig *et al*. 2007, 2011). Although there was a lack of cholesterol in the present study, cholesterol and cholesterol oxidation products were preserved in four samples. In addition, mono- and dihydroxy fatty acids (11-, 12-dihydroxy, C16, C18, C20), diacids (C4:0di–C10:0di), MAGs (C14–C20), ketones (C29–C35), and dehydroabietic acid are preserved in four, four, one, one and one samples respectively. The degree of variability is probably attributable to a number of different factors including, but not restricted to, site locations, differences between the samples and vessel uses as well as localized conditions for preservation and extraction methods.

5.8.5. GC-C-IRMS

For comparison, the data derived from the Havnø ceramic vessels are plotted alongside previously published (n = 56, Craig *et al*. 2007, 2011; Fischer and Heinemeier 2003; Heron *et al*. 2013) and unpublished (n = 30, Craig and Heron) data measured from Danish EBK and TRB vessels (Figures 5.21 and 5.22 and Appendix 4). In the following section, comparison is firstly made between six coastal sites (Figure 5.21), which are followed by comparison with 12 inland localities (Figure 5.22). Thus, the data from the Havnø vessels can be interpreted within the context of 19 Danish localities. The summary statistics for

each category of vessel included in this study are shown in Table 5.12. The $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ for all sampled sherds (n = 86) ranged from -32.8 to -12.0‰, and -34.7 to -14.6‰ respectively. The EBK vessels (n = 43), regardless of location, had a mean $\delta^{13}C_{16:0}$ value of -25.3 ± 4.5‰, and -27.2 ± 5.5‰ for $\delta^{13}C_{18:0}$ respectively, whereas the TRB funnel beakers (n = 43) had a mean $\delta^{13}C_{16:0}$ value of -27.9 ± 4.1‰, and -30.6 ± 3.6‰ for $\delta^{13}C_{18:0}$ respectively.

The coastal vessels (n = 36), regardless of epoch, had a mean $\delta^{13}C_{16:0}$ value of -23.0 ± 4.5‰, and -25.2 ± 5.3‰ for $\delta^{13}C_{18:0}$ respectively. When disaggregated according to culture, the pointed based vessels of the EBK (n = 23) had a mean $\delta^{13}C_{16:0}$ value of -22.5 ± 3.9‰, and -23.7 ± 4.9‰ for $\delta^{13}C_{18:0}$ respectively, whereas the funnel beakers of the TRB (n = 13) had a mean $\delta^{13}C_{16:0}$ value of -24.1 ± 5.5‰, and -27.8 ± 5.1‰ for $\delta^{13}C_{18:0}$ respectively. These data are plotted in Figure 5.21.

In general, the EBK vessels recovered from coastal localities plot within the marine ellipse established from a number of $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ obtained from northern European taxa (Craig *et al*. 2011, 2013; Dudd and Evershed 1998). However, there are a number of samples that plot between ellipses, indicating that a mixture of resources, including aquatic and terrestrial products were processed in these vessels. Similarly, the TRB funnel beakers recovered from coastal locations plot outside of the ellipses established from a number of northern European taxa (Craig *et al*. 2011, 2013; Dudd and Evershed 1998). While marine resources were unequivocally processed in a number of these vessels, freshwater, porcine and ruminant foodstuffs were also processed. These data are similar to the TRB vessels sampled from Havnø. Interestingly, one TRB funnel beaker from the stratified kitchen midden at Bjørnsholm had been used to process or store beeswax. This sample had a notably elevated $\delta^{13}C_{16:0}$ value of -12.0‰ and a $\delta^{13}C_{18:0}$ value of -23.9‰ (Heron *et al*. 2007).

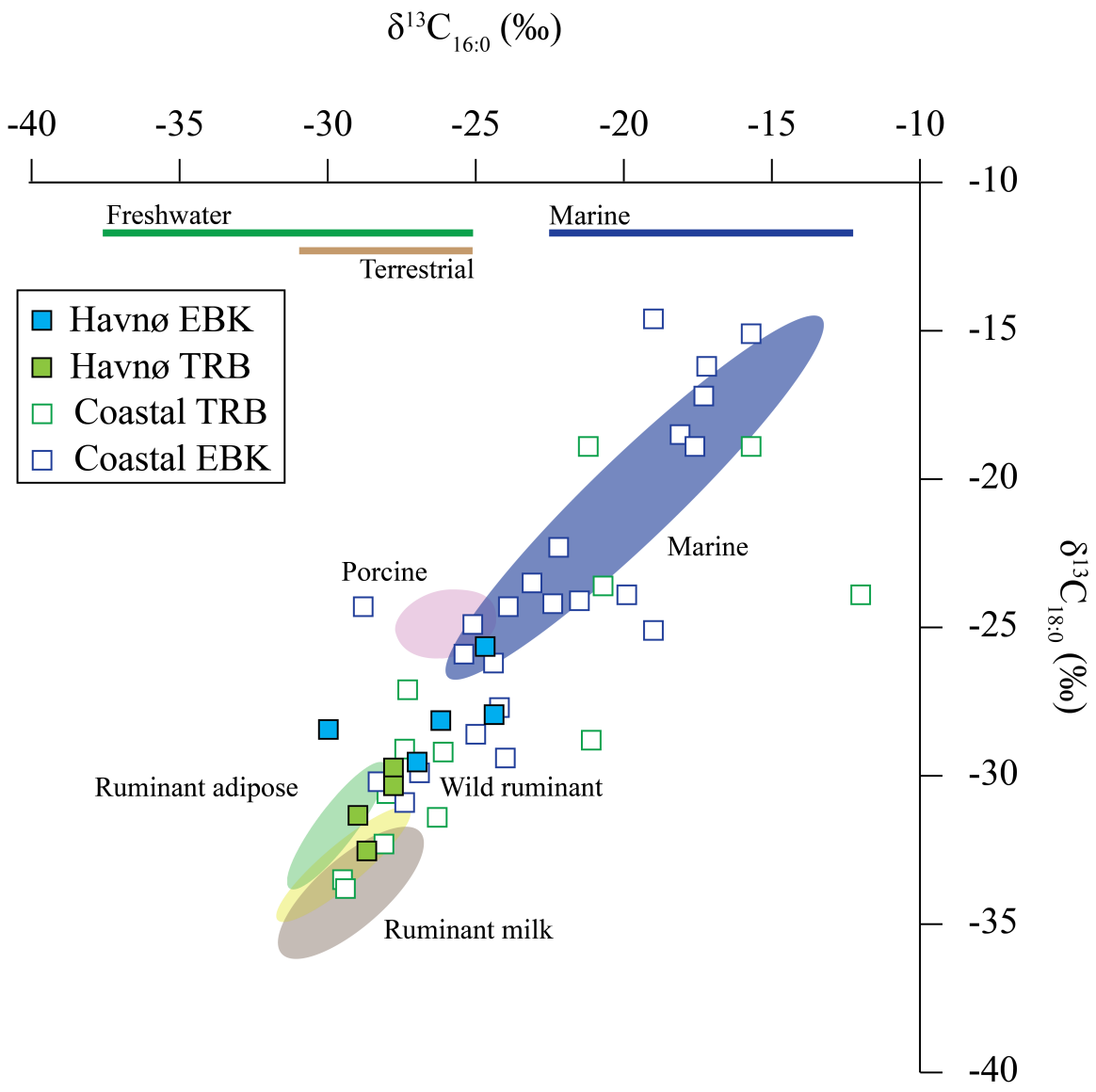


Figure 5.21: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from Havnø EBK and TRB vessels (n = 9) compared with coastal EBK (n = 23) and TRB (n = 12) vessels (Craig and Heron unpublished; Craig et al. 2007, 2011; Heron et al. 2013).

On the other hand, the inland vessels (n = 50), regardless of culture, had a mean $\delta^{13}C_{16:0}$ value of -29.2 ± 2.0‰, and -31.6 ± 2.1‰ for $\delta^{13}C_{18:0}$ respectively. When disaggregated, the pointed based vessels of the EBK (n = 20) had a mean $\delta^{13}C_{16:0}$ value of -28.6 ± 2.5‰, and -31.2 ± 2.6‰ for $\delta^{13}C_{18:0}$ respectively, whereas the TRB funnel beakers (n = 30) had a mean $\delta^{13}C_{16:0}$ value of -29.6 ± 1.5‰, and -31.9 ± 1.8‰ for $\delta^{13}C_{18:0}$ respectively. These data are plotted in Figure 5.22.

Sample group	Sample size	$\delta^{13}C_{16:0}$ (‰)	$\delta^{13}C_{18:0}$ (‰)	Δ13C (‰)
All vessels	86	-26.6 ± 4.5	-28.9 ± 4.9	-2.3 + 2.4
EBK vessels	43	-25.3 ± 4.5	-27.2 ± 5.5	-1.9 ± 2.5
TRB vessels	43	-27.9 ± 4.1	-30.6 ± 3.6	-2.7 ± 2.3
Coastal - all vessels	36	-23.0 ± 4.5	-25.2 ± 5.3	-2.2 ± 3.1
Coastal - EBK	23	-22.5 ± 3.9	-23.7 ± 4.9	-1.3 ± 2.6
Coastal - TRB	13	-24.1 ± 5.5	-27.8 ± 5.1	-3.7 ± 3.5
Inland - all vessels	50	-29.2 ± 2.0	-31.6 ± 2.1	-2.4 ± 1.8
Inland - EBK	20	-28.6 ± 2.5	-31.2 ± 2.6	-2.6 ± 2.2
Inland - TRB	30	-29.6 ± 1.5	-31.9 ± 1.8	-2.3 ± 1.5

Table 5.12: Summary statistics (± 1σ) for the various categories of vessels sampled in this study and in the studies by Craig et al. (2007, 2011) and Heron et al. (2013).

In general, the EBK and TRB vessels recovered from inland localities plot within the ruminant ellipses established from a number of northern European taxa (Craig *et al*. 2011, 2013; Dudd and Evershed 1998). However, there are a number of vessels that plot outside of these ellipses, indicating that a combination of products had been processed. There is at least one vessel that plots within the ellipse established for porcine, and a further two that are very near. In addition, there are a number of vessels that are depleted in both their $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values, and demonstrate that freshwater resources were processed.

5.8.6. Culinary change across the Danish Mesolithic-Neolithic transition

As evidenced by EA-IRMS the EBK vessels were, in general, enriched in ^{13}C when compared to those from inland localities regardless of culture and typology. While these data indicate that marine organisms had been processed, assessing the degree of temporal change in Denmark is problematic given the lack of sampled food crusts from TRB vessels recovered from coastal localitities. Although carbonized food crusts adhering to funnel beakers from other coastal sites in the region have demonstrated that aquatic resources continued to be processed (Craig *et al*. 2011), it would be unwise at the present to infer that a similar practice took place in Denmark based on these data alone. Since it is not yet possible to disentangle the potential constituents of the carbonized food crusts by EA-IRMS (Saul *et al*. 2014), the method should be used for screening purposes only (Craig *et al*. 2007).

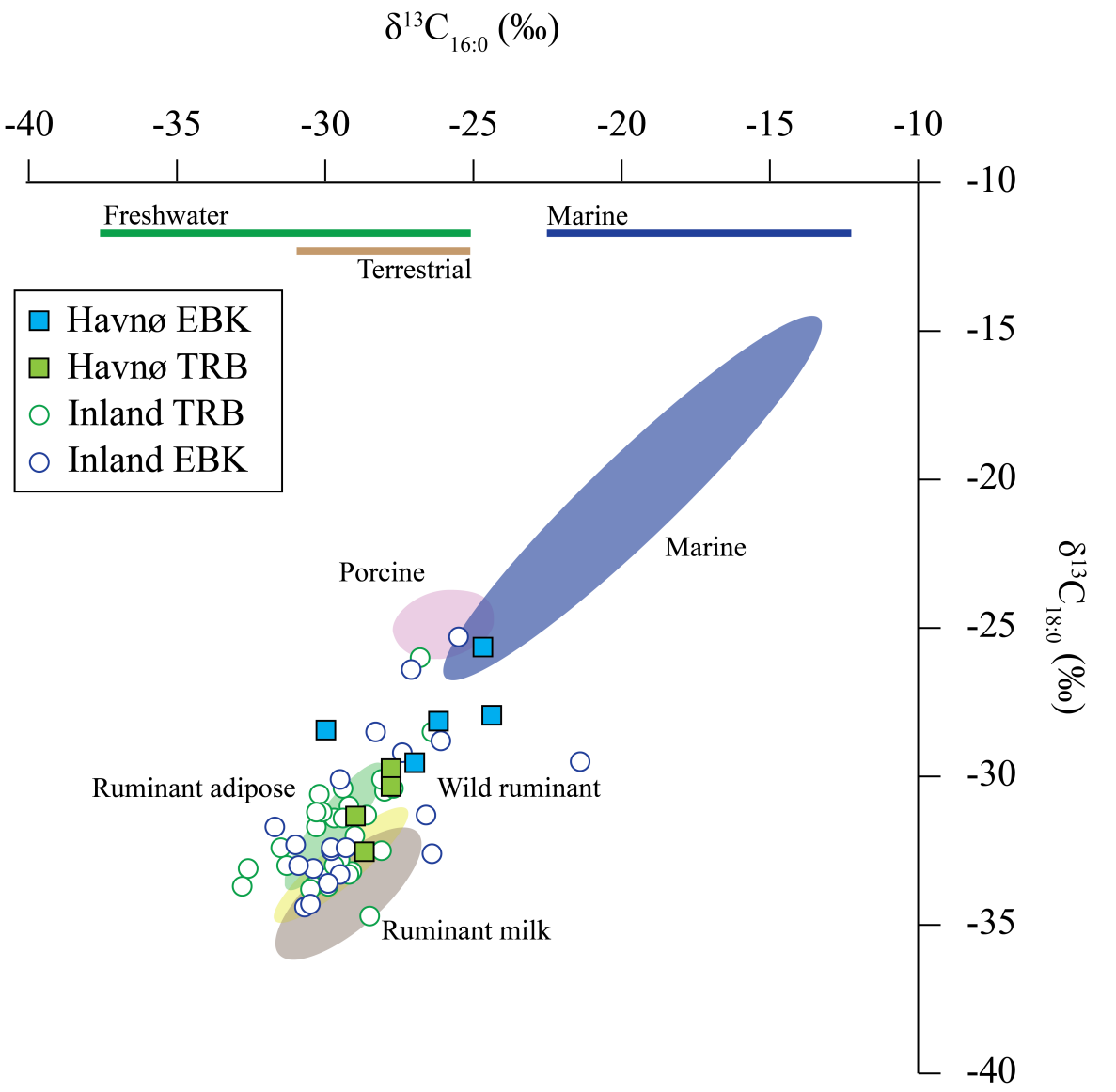


Figure 5.22: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from Havnø EBK and TRB vessels (n = 9) compared with inland EBK (n = 20) and TRB (n = 30) vessels (Craig and Heron unpublished; Craig et al. 2007, 2011; Fischer and Heinemeier 2003; Heron et al. 2013).

The molecular results obtained from EBK vessels from Havnø showed that a combination of different resources had been processed although there was not a single EBK vessel that had been chiefly used to process aquatic resources. These data contrast markedly with the contemporaneous sampled sherds from Gamborg Fjord, Ronæs Skov, Teglgård-Helligkilde, and Tybrind Vig as well as previous analyses that have demonstrated unequivocally that resources of aquatic origin had been processed (Craig *et al*. 2007, 2011; Heron *et al*. 2013).

In addition, the funnel beakers sampled from the kitchen midden appear to have been used in a similar manner, whereas the TRB ceramic vessel from Bjørnsholm demonstrated that products of aquatic origin had been processed after the Neolithic transition. While it is difficult to assess the degree of temporal change for coastal sites given the lack of molecular data, data obtained from vessels recovered from inland localitities have demonstrated that that freshwater fish and dairy fats had been processed (Craig *et al*. 2007).

In this study the GC-C-IRMS data demonstrated that a combination of resources had been processed in the EBK vessels at Havnø whereas the TRB vessels had been used to process ruminant products. These data differ to the results presented in Chapters 3, 4 and 6 which demonstrated that marine resources continued to be exploited, albeit in smaller quantities throughout the course of use at the kitchen midden. In addition these data differ somewhat to previously published data that has shown that aquatic resources continued to be processed across the Mesolithic-Neolithic transition (Craig *et al*. 2011).

Although the processing of plants in pointed based vessels of the EBK has been demonstrated elsewhere (Andersen 2009; Saul *et al*. 2012, 2013, 2014), the results from the ceramic vessels deposited at Havnø and Ronæs Skov emphasize the necessity for sampling sites differing in location and date. During the Danish EBK ceramic vessels were not solely used for the processing of aquatic resources. Similarly, despite evidence from northern Germany, which has demonstrated that dairy products were exclusively processed in the funnel beakers of the TRB (Saul *et al*. 2014), this practice does not appear to have been undertaken to the same degree in Denmark at the same time.

In 1995 it was suggested that the TRB ceramic vessels were used for the processing of domesticates (Gebauer 1995), which has been supported by recent ORA (Craig *et al*. 2007, 2011; Heron *et al*. 2007). In the study by Craig *et al*. (2011) lipids deriving from cow/sheep, dairy and porcine were identified. However, these types of foodstuffs were present in the ceramic vessels recovered from both coastal and inland localities. These data are somewhat different to other sampled sites in the region, for instance Neustadt and Wangels in northern Germany where there was no evidence that porcine products had been

processed despite the presence of domesticated pigs in the faunal assemblages (Glykou 2011; Saul *et al*. 2014). Suprisingly porcine products that were interpreted as wild boar were identified in several of the EBK ceramic vessels (Craig *et al*. 2011).

For comparison these data are disaggregated according to type of site in Figure 5.23. Overall it can be seen that the EBK ceramic vessels from Havnø are unusual, although not too dissimilar, since they plot with the majority of data obtained from vessels from inland settlements. Since there is only one sample from a contemporaneous kitchen midden (Åle), comparison is essentially meaningless.

In addition, the TRB data have been disaggregated and are plotted in Figure 5.24. In a similar manner it can be seen that the Havnø funnel beakers plot alongside the majority of the ceramic vessels derived from lakeshore settlements as well as the stray find from Roskilde Fjord. While several of the ceramic vessels from the kitchen middens (Bjørnsholm and Norsminde) had broadly similar $\delta^{13}C$ values, there were several that were notably depleted in both $C_{16:0}$ and $C_{18:0}$ and demonstrated unequivocally that products of marine origin had been processed. In addition, there was one funnel beaker from the Bjørnsholm kitchen midden that had been used for either processing or storing beeswax (Heron *et al*. 2007). Thus, these data highlight the importance for examining different types of sites in detail, and for not assuming the processing of resources of aquatic origin in the EBK and TRB, the latter supplemented by foodstuffs of terrestrial origin.

Owing to the revised criteria for identifying dairy products from archaeological ceramics (Craig *et al*. 2012), regardless of culture, location and typology, some of the vessels in this study demonstrated that dairy products may have been processed even in the EBK. However, these data equally fall within the aquatic range established (Craig *et al*. 2012). Since these data do not always tally with the archaeological evidence, it has been suggested that exchange with other groups or LBK groups to the south, or the exploitation of dairy products from wild ruminants post mortem may have taken place (Saul *et al*. 2014).

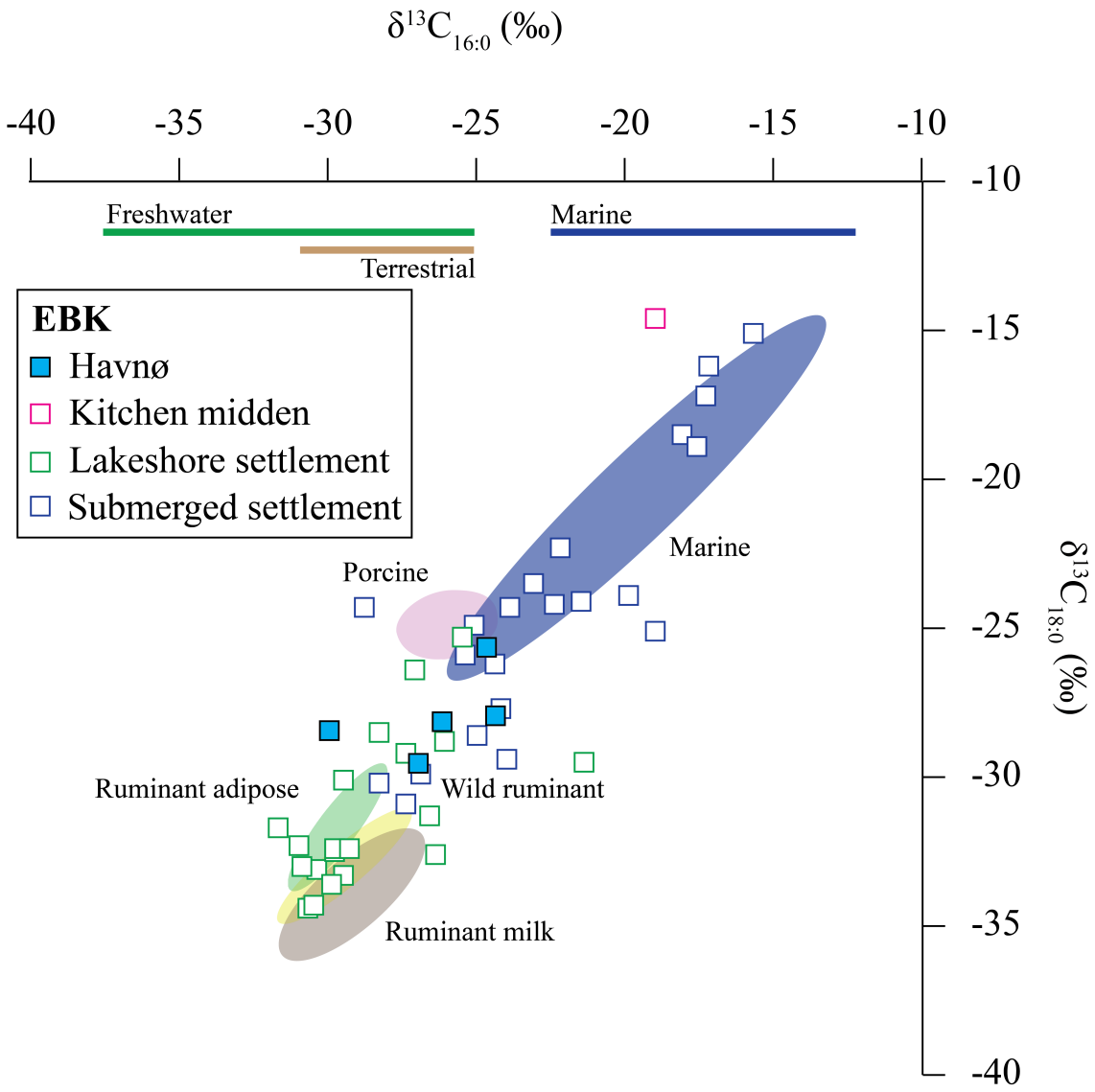


Figure 5.23: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from Havnø EBK vessels (n = 5) compared with EBK kitchen middens (n = 1), lakeshore settlements (n = 20), and submerged settlements (n = 22) vessels (Craig and Heron unpublished; Craig et al. 2007, 2011; Heron et al. 2013).

5.9. Conclusion

At Havnø there was a culinary change across the Mesolithic-Neolithic transition. On the whole the EBK ceramics had been used to process a combination of resources, whereas the funnel beakers had primarily been used to process ruminant foodstuffs as evidenced by GC-C-IRMS. There was only one EBK vessel that had been used for the processing of aquatic organisms. This is particularly interesting given the location of the site and somewhat

different when compared to the wider regional context. In general, the analyses have demonstrated the necessity for applying different analytical techniques to determine vessel use and culinary change across the Mesolithic-Neolithic transition. Via the powerful combination of the different methods available to us it is now possible to disaggregate economy and evaluate choices (Saul *et al*. 2014).

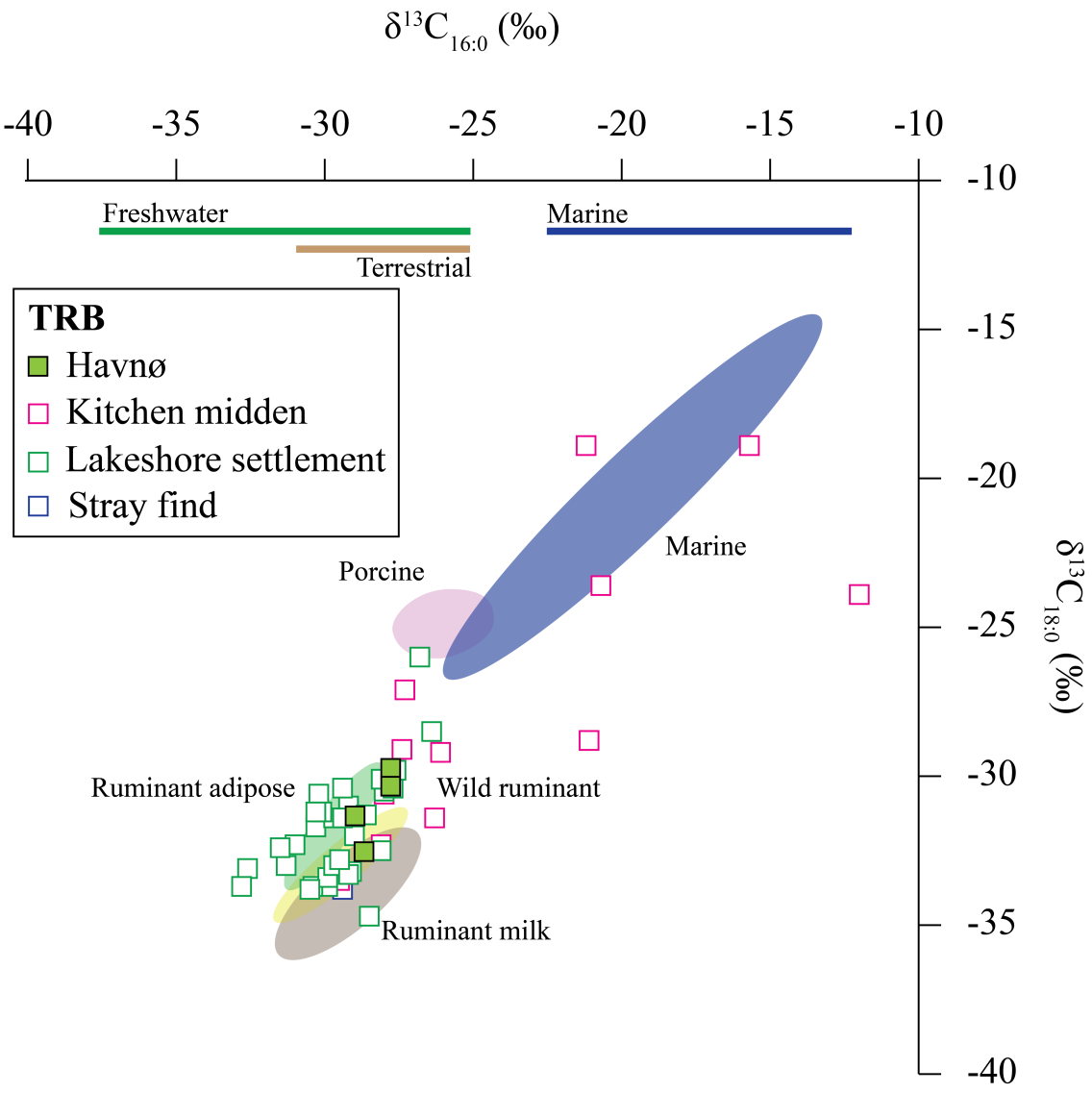


Figure 5.24: Compound-specific stable $\delta^{13}C$ values of individual $C_{16:0}$ and $C_{18:0}$ n-alkanoic acids extracted from Havnø TRB vessels (n = 4) compared with TRB kitchen middens (n = 12), lakeshore settlements (n = 31), and stray find (n = 1) vessels (Craig and Heron unpublished; Craig et al. 2007, 2011; Fischer and Heinemeier 2003; Heron et al. 2013).

Unfortunately the sample set was too small to identify spatial differences and/or processing events throughout the kitchen midden. In addition, there were no appreciable differences in the vessel type and the resources processed. Of the EBK ceramics, one small and one medium sized pointed based vessel had been used to process a combination of resources, whereas an additional medium sized pointed based vessel had been used to process marine products. The remaining pointed based vessels (medium and large) had similarly been used to process a combination of resources. However these two vessels had biomarkers consistent with aquatic resources but these were not absolute. Of the four funnel beakers three jars were represented and all had been used to process ruminant products.

At Havnø the appearance of the funnel beakers was synchronous with the general Neolithic package that rapidly replaced hunting, gathering and fishing (Richards *et al*. 2003b; Rowley-Conwy 2004). However, the introduction of farming was probably not as dramatic and sudden as previously envisaged, which is based, in part, on the data presented in Chapter 3. While the processing of aquatic resources of freshwater and marine origin continued after the introduction of domesticated fauna and flora elsewhere (Craig *et al*. 2007, 2011), only one EBK ceramic vessel from Havnø had evidence to suggest that similar products may have been processed. As such the culinary practices identified here support the view that the process of acculturation was more complex than has been previously inferred. The population historical approach for the process of acculturation in the region is based in part on two hypotheses: (1) that pastoralists travelled to the coast and began exploiting the abundant marine resources, or (2) that foragers resided in coastal localities, and through contact with nearby farmers, started to exploit domesticated fauna and flora, which supplemented their fishing, foraging and hunting way of life (Craig *et al*. 2011).

In conclusion, the study demonstrates that there is still much to be gleaned by the ORA of Danish ceramic vessels dating to the EBK and TRB. Significantly, the data are consistent with the appearance of domesticated fauna and flora. Although the analytical techniques yielded different data, aquatic resources of freshwater and marine origin, beeswax, cow/sheep, dairy, porcine, red deer and ruminant resources can be discriminated through a combination of EA-IRMS, GC-MS and GC-C-IRMS. Despite the fact that through the

ORA of ceramic vessels a picture can be built of what was processed in the vessels, this should not be relied on as the sole method and other lines of evidence should always be borne in mind. Since ceramic vessels are cultural artefacts, their function should not necessarily be a reflection of the local economy (Heron *et al*. 2007) or communal use (Saul *et al*. 2014).

6. Archaeoichthyological data from the Havnø kitchen midden

6.1. Introduction

There is little doubt that the Mesolithic and Neolithic peoples of Denmark consumed fish. This is supported by their presence within faunal assemblages as well as the numerous procurement implements that are routinely recovered during excavations (Enghoff 1994, 2011; Pedersen 2013; Ritchie 2010). The application of stable isotope analysis on EBK and TRB human bone collagen (Chapter 3), as well as recent developments in the molecular and isotopic characterization of lipids extracted from ceramic shards (Chapter 5) has demonstrated that an essential and sometimes significant proportion of human diets and vessel use consisted of aquatic resources, even at inland locations.

Fish remains have been recovered from coastal middens and urban sites and can reflect both human behaviour, for instance fishing techniques, preparation and consumption, trade, wealth and ritual, as well as the natural environment. Occasionally cultural remains are recovered from submerged sites including shipwrecks or settlements (Cardell 2004). Similarly, they can provide information regarding the waters fished as well as the techniques and technology used during their exploitation. Changes in species abundance or size may indicate changes in water temperature and/or quality brought about by environmental change or overexploitation (Jones 1988; O'Connor 1988). When present, migratory species may indicate either seasonal occupation at a site or a change in the economy towards seasonal fishing. Preserved fish (dried, pickled, salted or smoked) and their products, for instance Roman garum and other fermented sauces, have been widely traded and their production and consumption has been identified (Bateman and Locker 1982).

There is also a suite of scientific methods that can be applied to fish remains. Carbon and nitrogen stable isotope analysis of fish bone collagen has recently identified the movement of fish (Barrett *et al*. 2008, 2011; Orton *et al*. 2011), whereas the integration of use-wear

and protein residue analysis has shown that the processing of fish can be identified archaeologically (Högberg *et al*. 2009).

The abundance of fish remains constitutes an important source of information for studying the subsistence of the EBK and TRB occupants at the kitchen midden. The ichthyoarchaeological research whose results are discussed in this chapter focused on the following research questions:

- Subsistence: which taxa were exploited, in what quantities and in what manner? What can be said about the diversity of the fishing activities?
- Seasonality: what information do the identified taxa provide on the season of site occupation?
- Landscape: what information does the composition of the assemblage provide on the aquatic environment of the island's surroundings and on the exploited ecotones?
- Did any changes take place in the aforementioned aspects throughout the course of the occupation period?

In order to answer these questions an analysis of the six complete column samples excavated in the summer of 2011, and the hand-collected material from Havnø was undertaken. This involved a detailed analysis and documentation of the fish remains concerning the species of fish and their relative abundance, the skeletal elements present, the biology and distribution of the fish taxa, evidence of taphonomy, and the lengths of the subfossil fish. In addition, several questions were addressed, including whether there was a marked decrease in the size of the fish across the Mesolithic-Neolithic transition, what fishing methods are likely to have been employed, and whether there were similarities between the Havnø assemblage and contemporaneous kitchen middens and coastal settlement sites. The fish remains were identified by comparison with modern reference skeletons housed at The University of York. To address the biology and distribution of the fish taxa, a systematic examination of the available literature was undertaken. To obtain a comprehensive insight into fishing at Havnø the data from previous analyses are amalgamated. Published data was supplied by Ritchie (2010) and has been combined with

previous studies by the author (Robson 2010, 2011; Robson *et al*. 2012, 2013).

This chapter commences with a brief history of research. This will be followed by a review of the analysis of fish remains from archaeological contexts. The analysis of the fish remains from Havnø will then be presented. For inter-site comparison, three additional assemblages dating from the EBK and TRB cultures were analysed: the kitchen middens at Krabbesholm II, Norsminde and Thygeslund. In order to make a wider comparison, a review of previously published literature on fish remains derived from kitchen middens, coastal settlement sites and inland sites was also carried out. This was followed by an inter-site comparison between the east and west regions of Denmark.

6.2. Ichthyoarchaeology

6.2.1. History of research

In the past the recovery of fish remains during archaeological excavations was undertaken in a 'rather haphazard manner' (Wheeler and Jones 2009, 38). Prior to the 1960s the analysis of fish remains was not considered seriously so they are largely underrepresented in the literature. Since they were often deemed too fragile and small (Trolle-Lassen 1984), routine sorting by eye has not been conducive in their recovery. As a consequence smaller fish remains had often been overlooked. However, the lack of or inconsistency of sieving is perhaps the main methodological factor to explain their absence. For instance, over a 120-year period (1851-1971) only 21 Danish EBK sites yielded fish remains (Gron and Robson accepted). The inception of sieving from the late 1960s has, however, greatly improved their recovery and presently there are numerous well-analysed assemblages available (Figure 6.1). Over the last 44 years (1971-2015) 55 EBK sites in Denmark have yielded fish remains (Figure 6.2).

6.2.2. Species diversity in Denmark

There are over 200 species of fish that naturally occur within Danish waters (Appendix 5). Although fish reside and subsist in almost all aquatic habitats, species variation is dependant on a number of factors including the geographical area, water type (freshwater,

brackish/estuarine and marine), depth and quality. The main species of relevance are the bony fish (Osteichthyes) since other classes rarely preserve archaeologically (Wheeler and Jones 2009). However, there are a few skeletal elements of the cartilaginous fish (Chondrichthyes) that are commonly encountered, for instance dermal denticles, dorsal fin spines and calcified centra of sharks and rays (Enghoff 2011; Nicholson 2014).

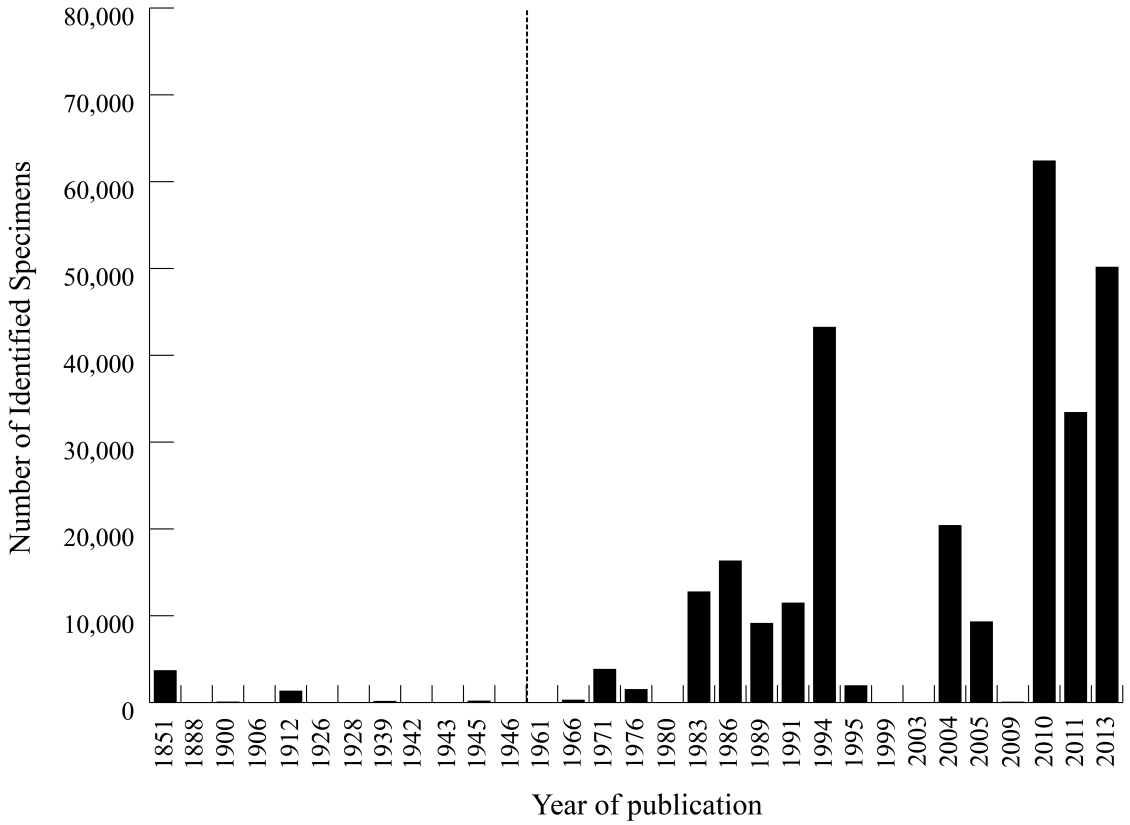


Figure 6.1: Year of publication and NISP. The dotted line approximately represents when sieving was employed during archaeological excavations. The first reported assemblage whereby sieving had been conducted was Ølby Lyng (Møhl 1971). It can be seen that when sieving has been employed the NISP has significantly increased.

6.2.3. Assemblage accumulation, taphonomy and recovery

Fish bone assemblages are often the result of human activities and include preparation, consumption or processing (Nicholson 1996). Inevitably characteristic distortion and corrosion can demonstrate either the consumption by humans or commensal animals especially when recovered from cesspit deposits (Jones 1984, 1986; Nicholson 1993).

However, it is necessary to take into consideration predators and scavengers that may have caused the accumulation of fish remains or the possibility that skeletal elements may have been present in the gastrointestinal tract of other fish. For instance, abandoned buildings and cave deposits may contain fish remains that were brought in by animals or dropped in their faeces (Conroy *et al*. 2005; Russ and Jones 2011; Wheeler and Jones 2009).

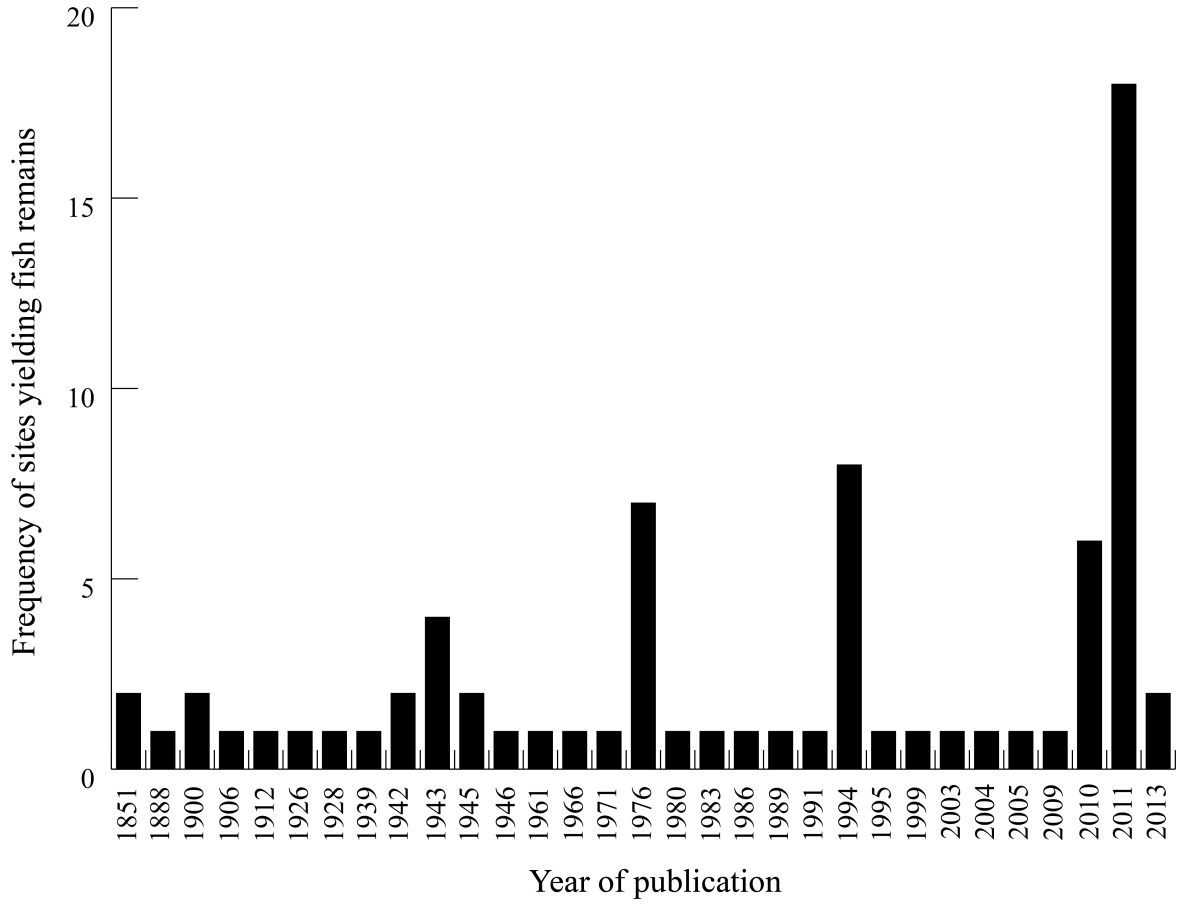


Figure 6.2: Year of publication and frequency of sites whereby fish remains are reported.

Larger elements in particular may possess characteristic distortion and marks caused by chewing, but smaller elements may pass through the gut undamaged (Nicholson 2000). The fish remains from submerged sites are often very well preserved but they require careful taphonomic consideration to ascertain whether they are naturally or culturally derived. Falling water levels (Nicholson 2014), a lack of food, or suffocation under ice (Noe-Nygaard 1987) have all been cited as reasons for mass mortality, and fish may also be stranded following a flood or the drying up of ditches or channels. The degree of bone

preservation may reflect rapid accumulation and deposition: otherwise scavenging, trampling and weathering are likely to be the result in the scattering and loss of skeletal elements (Bullock and Jones 1997; Jones 1999; Nicholson 1992). Recently percentage completeness and the size range of archaeological fish remains have aided our interpretation of site formation processes, and the effects from deposition in the burial environment to the analyst (Gron and Robson accepted).

Fish remains from different taxa vary in size, physical appearance and chemical composition that affect their survival prior, during and post deposition. Since the skeleton of rays and sharks is composed of ossified cartilage they rarely survive, although certain skeletal elements are often recovered because they resist diagenetic alteration, for instance dermal denticles, calcified or mineralized vertebral centra and teeth (Jones 1982; Nicholson 2014). Smaller remains are most likely to be preserved in waterlogged sediments or when they have become mineralized, for instance cesspits.

Careful sampling of archaeological deposits and sieving is essential. Large samples in the region of 100 litres maybe necessary to provide adequate numbers of fish remains (Nicholson 2014). It has been recommended that a 1 mm sized mesh should be employed during archaeological excavations (Enghoff *et al*. 2007; Jones 1982) as an adjunct to meticulous excavation techniques (Enghoff 1991, 2011; Payne 1972; Ritchie in print; Robson *et al*. 2013). The use of such would ensure a more holistic interpretation of fishing, including relative abundance, season of death and size (Enghoff 2011). Likewise it has been suggested that a 1 mm sized mesh should be used for the bulk processing of soil samples to aid in their recovery (Jones 1986). Thus, their absence at a site when sieving was not undertaken may imply that they were not recovered as opposed to a lack of exploitation (Enghoff *et al*. 2007).

6.2.4. Identification, age, season and size

Although the majority of skeletal elements can be identified to the family level, the diverse osteology within fish means that no single suite of skeletal elements can be used to identify all taxa (Nicholson 2014). Indeed some skeletal elements from certain taxa (Salmonidae

and Sparidae) may be difficult to identify to the lower taxonomic level. The most diagnostic elements in the majority of bony fish are usually the paired jawbones (dentary and premaxilla). Since fin elements are usually undiagnostic only a few can be identified (dorsal or anal fin spines). Pharyngeal elements from Sparidae and Cyprinidae are generally robust and are usually identifiable to species (Rutte 1962), but hybridization within Cyprinidae occurs (Cowx 1983). There are a number of fish that possess distinctive scales. Since they are usually fragmented archaeologically identification is only possible with considerable experience (Nicholson 2014).

The identification of fish remains requires access to a comprehensive reference collection of skeletons of known taxon. Smaller fish remains (<1.0 cm), including otoliths and scales require the use of a magnifying lens or microscope. A comprehensive review of fish anatomy, bone identification and recording is provided by Wheeler and Jones (2009).

The number of identified specimens (NISP) is most commonly used to report the relative abundance of taxa. During interpretation there are a number of variables that need to be taken into consideration. Some fish have species-specific elements, and some elements including those in the cranium are more characteristic than others for instance vertebrae. For example the majority of the eel skeleton can be identified to this species (Enghoff *et al*. 2007). By contrast, the majority of Gadidae and flatfish skeletal elements can easily be assigned to family but identification to a lower taxonomic level can be problematic. Moreover there are a number of Pleuronectidae cranial elements that can be differentiated to plaice, flounder or dab with certainty (Enghoff 1994; Wouters *et al*. 2007), and a limited number of skeletal elements for the Gadidae (Enghoff *et al*. 2007). In addition, the number of elements varies between species (Casteel 1976; Schmölcke and Ritchie 2010). For example the eel has a mean number of 114.5 vertebrae (Tesch 2003) that is considerably more when compared with cod (ca. 50). As such it can be often overrepresented in fish bone assemblages (Enghoff 1986). However, differential preservation including density, fat content and the size of the skeletal element have all been cited as reasons for their low recovery (Lepiksaar and Heinrich 1977; Mézes and Bartosiewickz 1994). The presence or absence by sample can also be useful for particularly large assemblages (Nicholson 2014).

Another metrical technique is to estimate the minimum number of individuals (MNI). However, it is often difficult to assess, calculate and has limited use since vertebrae are commonly or exclusively the only element encountered or recovered. In order to differentiate processed fish or the activities utilized it has been necessary to record a suite of skeletal elements and to separate the vertebrae into different regions of the spine (Enghoff 1996; Orton *et al*. 2014).

Age and season of death may be examined from the incremental growth ring analysis of fin spines, opercular, otoliths (Enghoff 1994; Mellars *et al*. 1980; Noe-Nygaard 1983), scales, and vertebrae (Brinkhuizen 1997). But interpretation of growth patterns requires experience, especially since annuli can often become distorted archaeologically or when the animal is alive, for instance damage and wear (Brinkhuizen 1997). Recently oxygen stable isotope analysis of fish otolith calcium carbonate is helping to identify the season of death (Hufthammer *et al*. 2010; Ritchie *et al*. 2013b). Although age correlates with size relative to individuals of the same species, it is rarely possible to assign species specific age classes based on size as growth rate is highly variable and dependent on external factors for example food availability (Nicholson 2014). However element size correlates with the size of the individual specimen and therefore it is possible to deduce the weight of flesh consumed and the size class structure of populations (Jones 1982).

Fish size can be estimated by one of two means: (1) either by comparison of the archaeological remains to skeletons of known size and taxon, or (2) reconstructed with precision by the individual measurements of selected remains or otoliths using published conventions (Enghoff 1994; Härkönen 1986). The season of death can additionally be examined through the statistical analysis of biometrical data (Wheeler and Jones 2009).

6.3. Materials and methods

6.3.1. Sampling

It was initially assumed that fish remains were not common throughout the kitchen midden (Ritchie 2010), which was probably due to the fact that sieving was not consistently

employed. However, the subsequent extraction of a complete column sample through the kitchen midden matrices demonstrated that fish remains could be recovered in reasonable quantities (Robson *et al*. 2013). To maximize recovery, six complete column samples were taken in August 2011. Of the six columns, the author excavated four, whereas two were excavated by one of the experienced volunteers during the August and September of 2011. All six columns measured 50 x 50 cm and were excavated with the intention that they were stratified incorporating both EBK and TRB material. They were taken from a number of different locations throughout the kitchen midden for intra-site comparison, both spatially and temporally (Figure 6.3).

Column ACAA was removed from the adjacent square to another column (YAA) that had been analysed previously (Robson *et al*. 2013). The column was located in the central part of the kitchen midden, whereas column ACDD was extracted from the south. Two columns (AFCF and AFDC) located one metre north of column ACDD were removed. Since one of the columns (AFCF) did not measure 50 x 50 cm due to the fact that the trenches had been opened for a number of years and the sections had collapsed or had been re-cut in places, a second column (AFDC) was excavated in the adjacent square. However the material obtained from this column (AFDC) may be unreliable since the sample derived from a heavily disturbed area of unknown age (Andersen personal communication 2012). Two columns (AFAA and AFBE) were excavated to the west of the cutting made during the initial excavations at the kitchen midden (Madsen *et al*. 1900). A thorough description of each column sample employed is provided in Appendix 5.

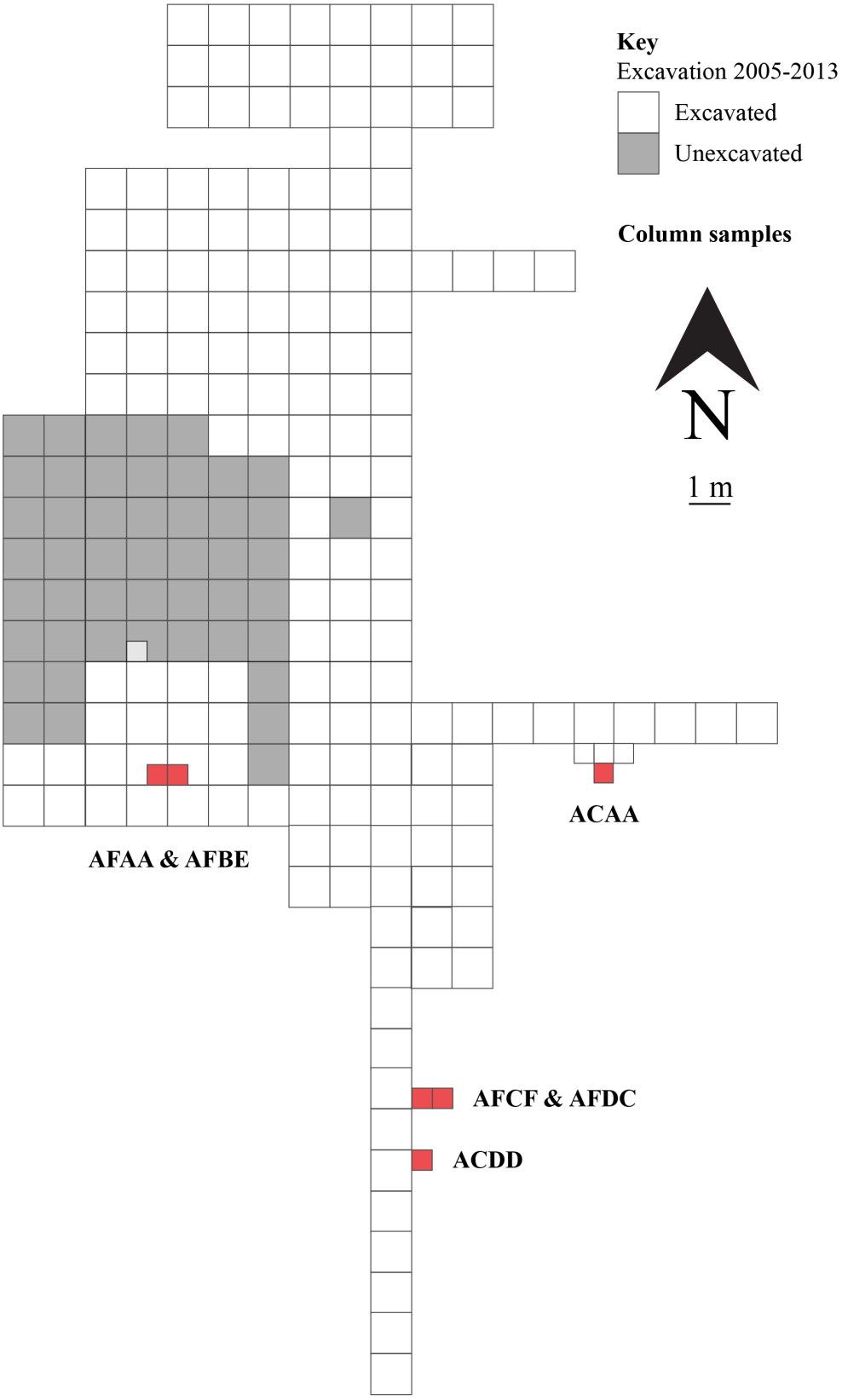


Figure 6.3: The full extent of the Havnø excavations and the location of the column samples in this study.

The matrices from all columns were excavated using a variety of hand tools, including brush, trowel and spade. Where possible the brush was favoured since the method has proven to increase the rate of recovery (Robson 2011). During the excavation of the columns the fish remains were extracted. The matrices were then screened through a nested column of sieves (2.5, 1.0 and 0.5 mm fractions), ensuring that the smallest of anthropogenic materials were recovered (Robson *et al*. 2013). In addition, a number of soil samples were removed from different layers throughout many of the columns. All of the anthropogenic material encountered was plotted in a 3-dimensional coordinate system using a dumpy level. The individual materials from each of the layers were either bagged or placed in glass vials and were documented by field notes, plan and photography.

Since not all of material had been previously sieved (Ritchie 2010) numerous fish remains are likely to have been lost. With this in mind, during the August 2011 excavations all of the matrices were sieved through either a 4.0 or a 1.0 mm sized mesh (Figure 6.4). The material collected in the sieve as well as the hand-collected material was documented on site before being removed. Søren H. Andersen sent additional material in Autumn 2011, whereas the outstanding fish remains recovered between August 2011 and 2013 were collected in Spring 2014. The majority of these samples included hand collected material but also fish remains that had been recovered during the post excavation processing of bulk samples.

6.3.2. Laboratory analysis

To remove residual matrices, all of the materials were dry screened in the laboratory through a nested column of sieves (4.0, 2.5 and 1.0 mm fractions). The fish remains were then subsequently separated from other anthropogenic material and examined under a stereomicroscope between 10.5-45.0x magnifications or by the naked eye. The material (bones, dermal structures and scales) was identified through side-by-comparison with modern reference skeletons of known taxa housed at the BioArCh laboratory at The University of York. The reference collection has in excess of 700 specimens that are known to reside in northern European aquatic environments (Jones 1988). For the identification of some of the more challenging specimens, Andrew Jones was consulted. Additional

information on bone morphology, taxonomy, biology and methods of identification was consulted from numerous publications (Cannon 1987; Casteel 1976; Conroy *et al*. 2005; Lepiksaar 1983; Maitland and Linsell 2009; Muus and Dahlstrøm 1964; Radu 2005; Wheeler and Jones 2009; Whitehead *et al*. 1989), and electronic resources (www.fishbase.org; www.fishbone.nottingham.ac.uk).

Figure 6.4: Photograph of the on-site sieve with a mesh size of 1.0 mm.

For the majority of the fish remains, an estimation of total fish length (hereafter TL) was achieved by direct comparison of the skeletal element confidently identified to genus and species with modern fish skeletons. These were of known length and housed in the reference collection at The University of York.

Despite the numerous regression equations that are available in the literature to estimate TL, only a selected few were applied. The reasons for this were multifold. Since the majority of the specimens were <1 cm in size an accurate measurement was not always possible. In addition, it was not possible to identify all of the specimens to the genus or species levels. Furthermore, NISP values derived from previous studies demonstrated that

the fish faunal assemblage was predominantly composed of the European eel (Ritchie 2010; Robson 2010, 2011). Thus, it was judged unlikely that the time invested would have justified the output.

For the European eel metric data was obtained on a number of skeletal elements, including ceratohyals (n = 66), cleithra (n = 42), and dentaries (n = 40). For the Atlantic cod, metric data was obtained on first vertebrae (n = 9). All measurements were undertaken with digital calipers to two decimal places in accordance with established methods (Enghoff 1986, 1994; Morales and Rosenlund 1979). The European eel and Atlantic cod total lengths were determined by means of regression equations based upon Enghoff (1986, 1994).

Quantification included a count of the total number of identified specimens (NISP) of each taxon. In general, MNI was not calculated given the inherent issues associated with its assessment (Wheeler and Jones 2009). Likewise the material was not weighed due to the potential for intra-site variation in preservation conditions (Noe-Nygaard 1987). Lastly, noteworthy characteristics including burning, butchery, and distortion and gnawing were recorded to assess taphonomy.

6.4. Results

6.4.1. Quantity

Over ten thousand fish remains were collected during the excavations at the kitchen midden; however, they represent a fraction of the overall material that had survived since deposition. It is impossible to estimate the total number of fish remains at the kitchen midden given its size.

6.4.2. Preservation

The fish remains were concentrated in the midden proper, where the midden sequence was thickest and most favourable for preservation (Figure 6.5), and this was proven by the presence of scales and dermal denticles that are more susceptible to degradation. Only one specimen was recovered to the north of the midden proper and probably reflects less

favourable conditions for preservation due to the lack of shell deposits in this area of the site. On the other hand numerous fish remains were recovered from higher up in the midden sequence representing younger occupation periods that were equally as favourable for preservation. However numerous fish remains probably did not preserve due to the pre-depositional actions of the Havnø inhabitants (for instance descaling, gutting, butchery, effects of cooking, boiling, discard and trampling) as well as post-depositional taphonomic processes such as marine transgressions.

In the areas of the kitchen midden where fish remains were recovered, it would appear that they were not markedly altered after deposition. The majority of the material had survived reasonably well and there was little evidence of flaking off of the outside of the bone (Brinkhuizen 2006). In addition, conditions for preservation varied between contexts.

6.4.3. Contexts

The fish remains derived from numerous contexts throughout the kitchen midden although they did not appear to form a uniform horizontal or vertical distribution. Occasionally they were recovered in small concentrations that probably corresponded to individual depositional events. In addition, they were recovered from a number of features, including hearth fills and secondary pits that had been dug into the kitchen midden. It is without a doubt that these represented younger depositional episodes.

At the present it is impossible to assign every specimen to cultural epoch. This is based, in part, on a lack of contextual data for some of the samples. However, a total of 3,415 fish remains could be assigned to period (Table 6.1). Of these, 2,601 were recovered from contexts dating to the EBK, whereas 302 belonged to transitional contexts. In total, 512 fish remains were derived from contexts dating to the Neolithic. Since the AMS radiocarbon dates demonstrated that the kitchen midden continued to accumulate from the TRB to the DC cultures these specimens have not been disaggregated.

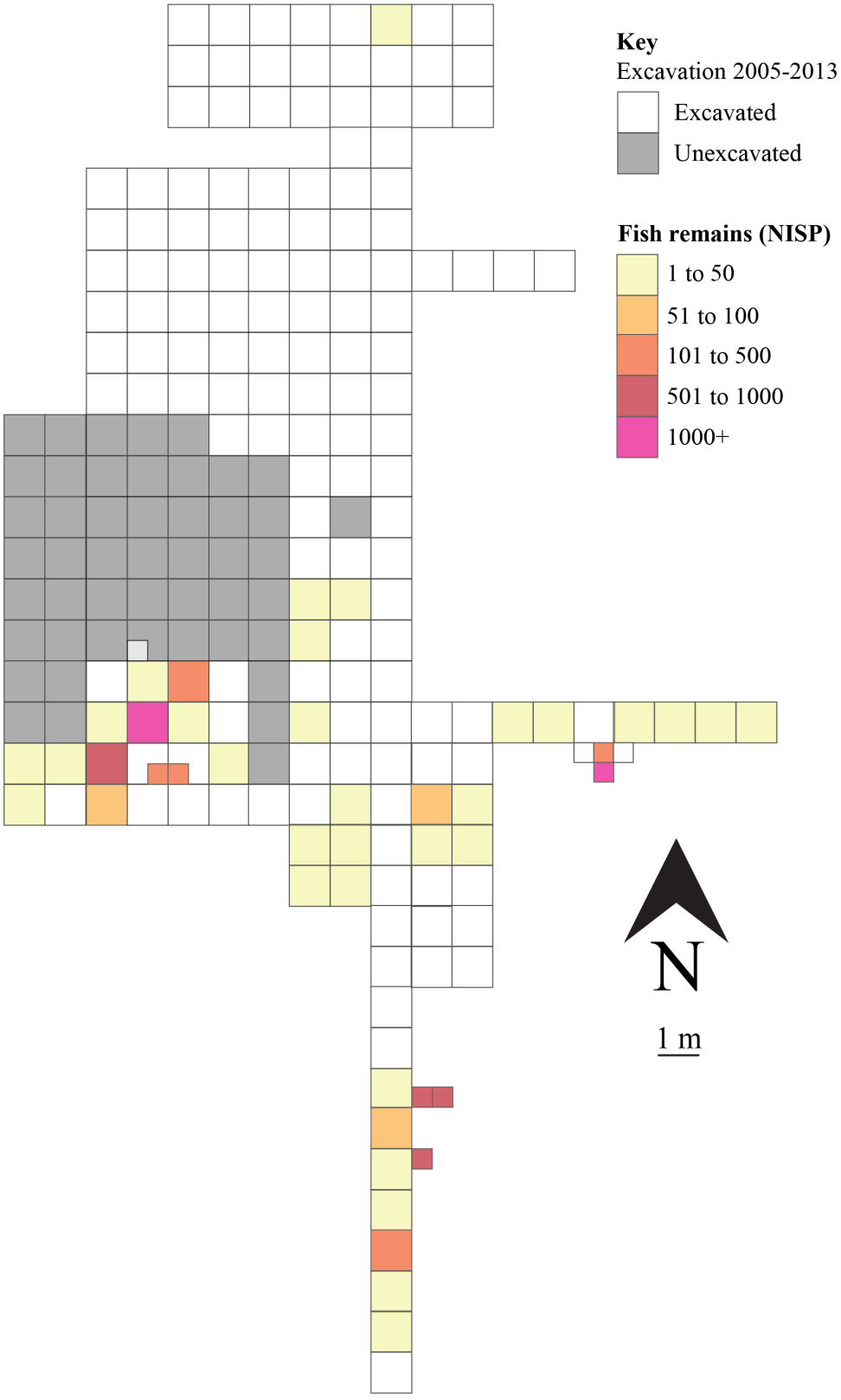


Figure 6.5: The full extent of the Havnø excavations and the distribution pattern of the fish remains per square metre in this study combined with previous studies (Ritchie 2010; Robson 2011).

Cultural epoch	Column					Other	Totals
	ACAA	AFAA	AFBE	AFCF	AFDC		
TRB-DC	1	88	8	77	280	58	**512**
EBK/TRB	15	135	120		32		**302**
EBK	1403	182	129	84	66	737	**2601**
Totals	**1419**	**405**	**257**	**161**	**378**	**795**	**3415**

Table 6.1: Fish remains presented according to cultural epoch.

6.4.4. NISP and NF

The fish taxa identified are listed in Table 6.2. A total of 10,286 fish remains were identified. Of these, 2,675 specimens could be identified to the species, genus or family levels. The majority of the specimens (*n* = 1,471, 54.9% of NISP) derived from materials that were either collected by hand or in the 4 mm sieve during the excavations or as a result of the post excavation processing. The remainder (*n* = 1,204; 45.1% of NISP) were recovered from the six column samples that were excavated through the midden sequence. Twenty-seven fish families were represented. Vertebrae constituted 66.8% (NISP = 1,787) of the assemblage with 33.2% (NISP = 888) consisting of cranial and other skeletal elements. The data shown in Table 6.3 are based on those 2,675 fish remains, and have been divided according to recovery technique and layer for each of the column samples.

Family	**Genus and species**	**Common name**	**Habitat use and life history**
Squalidae	*Squalus acanthias*	Spurdog	Marine; brackish; benthopelagic; oceanodromous
Clupeidae	*Clupea harengus*	Atlantic herring	Marine; brackish; benthopelagic; oceanodromous
Engraulidae	*Engraulis encrasicolus*	European anchovy	Marine; brackish; pelagic-neritic; oceanodromous
Esocidae	*Esox lucius*	Northern pike	Freshwater; brackish; demersal; potamodromous
Salmonidae	*Salmo trutta*	Sea trout	Marine; freshwater; brackish; pelagic-neritic; anadromous
Salmonidae	*Salvelinus alpinus alpinus*	Arctic char	Marine; freshwater; brackish; benthopelagic; anadromous
Anguillidae	*Anguilla anguilla*	European eel	Marine; freshwater; brackish; demersal; catadromous
Belonidae	*Belone belone*	Garfish	Marine; brackish; pelagic-oceanic; oceanodromous
Gasterosteidae	*Gasterosteus aculeatus*	Three-spined stickleback	Marine; freshwater; brackish; benthopelagic; anadromous
Gasterosteidae	*Spinachia spinachia*	Sea stickleback	Marine; brackish; benthopelagic; non-migratory
Cyprinidae	*Abramis brama*	Freshwater bream	Freshwater; brackish
Cyprinidae	*Rutilus rutilus*	Roach	Freshwater; brackish; benthopelagic
Cyprinidae	*Tinca tinca*	Tench	Freshwater; brackish; demersal; potamodromous
Gadidae	*Gadus morhua*	Atlantic cod	Marine; brackish; benthopelagic; oceanodromous
Gadidae	*Merlangius merlangus*	Whiting	Marine; brackish; benthopelagic; oceanodromous
Percidae	*Perca fluviatilis*	European perch	Freshwater; brackish; demersal
Moronidae	*Dicentrarchus labrax*	European sea bass	Marine; freshwater; brackish; demersal; oceanodromous

Family	**Genus and species**	**Common name**	**Habitat use and life history**
Carangidae	*Trachurus trachurus*	Atlantic horse mackerel	Marine; pelagic-neritic; oceanodromous
Sparidae	*Pagellus bogaraveo*	Blackspot sea bream	Marine; benthopelagic
Sparidae	*Spondyliosoma cantharus*	Black sea bream	Marine; benthopelagic; oceanodromous
Labridae	*Ctenolabrus rupestris*	Goldsinny-wrasse	Marine; reef-associated
Ammodytidae	*Ammodytes tobianus*	Small sandeel	Marine; brackish; demersal
Trachinidae	*Trachinus draco*	Greater weever	Marine; demersal
Scombridae	*Scomber scombrus*	Atlantic mackerel	Marine; brackish; pelagic-neritic; oceanodromous
Callionymidae	*Callionymus lyra*	Dragonet	Marine; demersal
Anarhichadidae	*Anarhichas lupus*	Atlantic wolfish	Marine; demersal; oceanodromous
Zoarcidae	*Zoarces viviparus*	Eelpout	Marine; brackish; demersal
Mugilidae	*Liza ramada*	Thinlip grey mullet	Marine; freshwater; brackish; pelagic-neritic; catadromous
Triglidae	*Chelidonichthys c uculus*	Red gurnard	Marine; demersal
Cottidae	*Taurulus bubalis*	Longspined bullhead	Marine; brackish; demersal; non-migratory
Scopthalmidae	*Scophthalmus rhombus*	Brill	Marine; demersal; oceanodromous
Pleuronectidae	*Platichthys flesus*	European flounder	Marine; freshwater; brackish; demersal
Pleuronectidae	*Pleuronectes platessa*	European plaice	Marine; brackish; demersal; oceanodromous

Table 6.2: Identified fish species with data on habitat use and life history (Froese and Pauly 2015). Note that the data has been tabulated taxonomically according to Whitehead et al. (1989).

Column							
Layer	**ACAA**	**ACDD**	**AFAA**	**AFBE**	**AFCF**	**AFDC**	**Totals**
1	1		2	1			4
2	2	59	22	1		47	131
3	34	49	30	25	10	36	184
4	88	22	21	15	26	7	179
5	148	13	22	27	25	14	249
6	254	13		3	14	32	316
7	76	12			5	17	110
8	21						21
9	6						6
10	1						1
Cleaning				3			3
Totals	**631**	**168**	**97**	**75**	**80**	**153**	**1204**
Collected by hand, 4 mm mesh or bulk sample							**1471**
Total							**2675**

Table 6.3: Distribution of fish remains in the six column samples by layer as well as those specimens that were either collected by hand, recovered in the sieve or from during post excavation.

6.4.5. Fish taxa and their relative frequencies

Fish species from 27 families were represented. Identification to the species taxonomic level was attempted, but 10 specimens from eight families were identified, respectively, to the following groupings: garfish/Atlantic saury; bream/roach; bream/rudd; pollock/saithe; blackspot sea bream/black sea bream; thicklip grey mullet/thinlip grey mullet; grey gurnard/red gurnard and flounder/plaice. Of the 27 families, ten equally could not be further identified to the lower genus and species taxonomic levels (Table 6.4). Of these ten families, three Clupeidae species, two species from each of the Salmonidae and Gasterosteidae families, seven Cyprinidae species, six Gadidae species, one species from each of the Sparidae and Gobiidae families, two species from each of the Triglidae and Scopthalmidae, and three Pleuronectidae species had been identified previously (Enghoff 2011). Consequently, the archaeological specimens representing these families were identified, respectively, according to the following groupings: for Clupeidae, herring/anchovy/shad; for Salmonidae, sea trout/Atlantic salmon; for Gasterosteidae, three-spined stickleback/fifteen-spined stickleback; for Cyprinidae, white bream/common

bream/Crucian carp/common carp/roach/rudd/tench; for Gadidae, cod/haddock/whiting/pollock/saithe/ling; for Sparidae, black sea bream; for Gobiidae, black goby; for Triglidae, grey gurnard/tub gurnard; for Scopthalmidae, turbot/brill; for Pleuronectidae, dab/plaice/flounder. Moreover, it was not possible to identify one specimen beyond the subclass (Elasmobranchii), whereas 28 specimens could not be identified beyond the order level (Perciformes and Pleuronectiformes).

The European eel completely dominated the fish fauna assemblage, constituting 61.4% of the total NISP. Next in relative frequency was Atlantic cod at 7.1%. This was followed by Pleuronectidae (right-eyed flounders) at 5.2%, Gadidae at 5.1%, Clupeidae at 3.4% and flounder at 2.7%. At least 30 species together constituted the remaining 15.1%.

The species spectrum comprised of euryhaline and to a lesser extent freshwater and marine fish, the majority of which migrate between the two (Table 6.5). Except for column AFAA (28.9%), migratory species dominated, constituting between 48.6% and 90.5% of NISP. The migratory taxa have been disaggregated according to anadromy and catadromy.

Anadromous species are fish that migrate into freshwater from marine or brackish environments to spawn. Some spawn just above the brackish-freshwater ecotone, whereas others in the upper reach of freshwater systems (Brinkhuizen 2006). At least four species of fish identified in the material are anadromous: sea trout, Arctic char, three-spined stickleback and fifteen-spined stickleback. Noteworthy is the Arctic char ceratohyal that had not been previously identified in Danish EBK or TRB fish bone assemblages.

Catadromous species are fish that migrate from fresh or brackish waters to marine environments to spawn. Two of the identified species of fish are catadromous: European eel and European flounder. At least eight cranial and other elements as well as 26 vertebrae derived from flounder. In addition, 39 dermal denticles were recovered. Since they are a characteristic of flounders, many of the other Pleuronectidae remains probably derived from this species.

Taxon	Sample							T	%
	ACAA	ACDD	AFAA	AFBE	AFCF	AFDC	O		
Elasmobranchii							1	1	0.0
Spurdog	1		2	3			1	7	0.3
Clupeidae							91	91	3.4
Atlantic herring		3	2	1		1	16	23	0.9
European anchovy		1					4	5	0.2
Northern pike	13						25	38	1.4
Salmonidae	7	2	5	2	2	2	23	43	1.6
Sea trout							2	2	0.1
Arctic char							1	1	0.0
European eel	561	122	23	19	57	123	737	1642	61.4
Garfish	1					1	4	6	0.2
Garfish/Atlantic saury		1						1	0.0
Gasterosteidae							2	2	0.1
Three-spined stickleback		3				1	38	42	1.6
Fifteen-spined stickleback							1	1	0.0
Cyprinidae	7	2			2	1	15	27	1.0
Freshwater bream	1				1		1	3	0.1
Freshwater bream/roach							1	1	0.0
Freshwater bream/rudd							1	1	0.0
Roach		1	9		1		9	20	0.7
Roach/perch		6	1				1	8	0.3
Tench							2	2	0.1
Gadidae	6	18	7	4	5	9	87	136	5.1
Atlantic cod	8		11		5		166	190	7.1
Whiting						1		1	0.0
Pollock/saithe			2				1	3	0.1
European sea bass			2				2	4	0.1
Atlantic horse mackerel							2	2	0.1

Taxon	Sample							T	%
	ACAA	ACDD	AFAA	AFBE	AFCF	AFDC	O		
Sparidae							1	1	0.0
Blackspot sea bream							1	1	0.0
Blackspot sea bream/Black sea bream	1							1	0.0
Black sea bream						1		1	0.0
Goldsinny-wrasse	1							1	0.0
Small sandeel	1							1	0.0
Greater weever	2						2	4	0.1
Atlantic mackerel	4					6	16	26	1.0
Gobiidae		1						1	0.0
Dragonet	1	2						3	0.1
Atlantic wolfish							3	3	0.1
Eelpout						1	4	5	0.2
Triglidae			1					1	0.0
Thicklip grey mullet/thinlip grey mullet		1						1	0.0
Thinlip grey mullet				1				1	0.0
Grey gurnard/red gurnard		1						1	0.0
Red gurnard	1				1			2	0.1
Longspined bullhead							1	1	0.0
Perciformes			2				25	27	1.0
European perch	1						7	8	0.3
Pleuronectiformes							1	1	0.0
Scopthalmidae		1				1		2	0.1
Scopthalmidae/ Pleuronectidae	4		3	2	2	3	32	46	1.7
Brill							1	1	0.0
Pleuronectidae	6	2	24	18	4	1	84	139	5.2
European flounder	3			14	3	1	52	73	2.7

Taxon	Sample							T	%
	ACAA	ACDD	AFAA	AFBE	AFCF	AFDC	O		
European flounder/European plaice							1	1	0.0
European plaice	1	1	3	8			6	19	0.7
NISP	**631**	**168**	**97**	**72**	**83**	**153**	**1471**	**2675**	100.0
Unidentifiable	788	451	308	185	83	225	5571	7611	
Totals	**1419**	**619**	**405**	**257**	**166**	**378**	**7042**	**10286**	

Table 6.4: Fish identified in the material with quantification. Key: O, other, T, total.

No less than 10 of the identified species are marine fish, a number that can tolerate brackish to freshwater throughout their life histories: spurdog, Atlantic herring, European anchovy, garfish, garfish/Atlantic saury, Atlantic cod, whiting, small sandeel, Atlantic mackerel, eelpout and red gurnard. A total of seven specimens deriving from spurdog were identified. Since the skeletal elements from this species are poorly ossified, some may not have been preserved. Ninety-one Clupeidae specimens were identified, whereas 23 could be identified to the Atlantic herring. Herring are a pelagic species that reside in shoals of the same size and age (Brinkhuizen 2006). Schools of young herring can tolerate brackish to freshwater, consequently the numerous small remains that could not be further identified beyond the family level (Clupeidae) probably belonged to this species.

Five specimens deriving from the European anchovy were identified. This species has only been previously identified from the Krabbesholm II kitchen midden (*n* = 117, Enghoff 2011). Six specimens deriving from garfish were identified, whereas one specimen could not be differentiated between the garfish and Atlantic saury. Seven percent of the material belonged to the Atlantic cod. Since the majority of the remains derived from smaller individuals, they were probably caught in brackish waters. One specimen deriving from whiting and sandeel was identified. In total 26 specimens belonging to Atlantic mackerel were identified although it is possible that more may have been present since the skeletal

elements from this species are poorly ossified. Lastly five eelpout specimens as well as two specimens deriving from the red gurnard were identified. The latter has not been previously identified in Danish EBK or TRB fish bone assemblages, and presently has a more southerly distribution.

Habitat use and life history	**Family**	**Taxon**	**NISP**	**%**
Anadromous	Salmonidae; Gasterosteidae	Sea trout, Atlantic char; three-spined stickleback, fifteen-spined stickleback	91	3.4
Brackish/marine	Squalidae; Clupeidae; Engraulidae; Belonidae; Belonidae/Scomberesocidae; Gadidae; Ammodytidae; Scombridae; Zoarcidae; Triglidae	Spurdog; Atlantic herring; European anchovy; garfish; garfish/Atlantic saury; cod, whiting; small sandeel; Atlantic mackerel; eelpout; red gurnard	499	18.7
Catadromous	Anguillidae; Pleuronectidae	European eel; European flounder	1874	70.1
Catadromous/ brackish/marine	Gobiidae	Gobids	1	0.0
Catadromous/ marine	Pleuronectiformes; Pleuronectidae/Scopthalmidae	Flatfishes; right eye flounders/turbots	47	1.8
Freshwater/ brackish	Cyprinidae; Esocidae; Perciformes; Cyprinidae/Percidae; Percidae; Cottidae	Freshwater bream, roach, tench; northern pike; perch-likes; minnows or carps/perches; perch; longspined bullhead	136	5.1
Freshwater/ brackish/marine	Moronidae; Mugilidae	European sea bass; thinlip grey mullet	6	0.2
Marine	Elasmobranchii; Carangidae; Sparidae; Labridae; Trachinidae; Callionymidae; Anarhichadidae; Scopthalmidae	Sharks, skates and rays; Atlantic horse mackerel; blackspot sea bream, black sea bream; goldsinny-wrasse; greater weever; dragonet; Atlantic wolfish; turbots	21	0.8
Total			**2675**	**100**

Table 6.5: Summary of fish identified in the material grouped according to habitat use and life history.

At least six of the identified species are stationary freshwater fish that can also reside in weakly brackish water: northern pike, freshwater bream, roach, tench, perch and longspined bullhead. These commonly occur in stagnant or gently flowing freshwater – in an area known as the bream zone (Brinkhuizen 2006). Unfortunately 62 specimens could not be further identified beyond the order or family levels (Cyprinidae, Perciformes and Percidae).

A number of cranial and other elements as well as vertebrae deriving from Scopthalmidae and Pleuronectidae (left and right-eyed flatfishes) could be identified to the species level. Seven cranial and other elements as well as 13 vertebrae could be identified to brill and plaice respectively. However, the majority of the Pleuronectidae remains probably derived from flounder. This assumption is based, in part, on the 39 dermal denticles that were identified in the assemblage since they are absent in other species of the Pleuronectidae family. In addition, the carbon and nitrogen stable isotope analysis undertaken on Pleuronectidae bone collagen demonstrated that the specimens were, in general, lower down in the trophic level hierarchy, which is a characteristic of their life history and habitat use (Chapter 3).

Only 21 remains derived from marine taxa: sharks, skates and rays, Atlantic horse mackerel, blackspot sea bream, black sea bream, goldsinny-wrasse, greater weever, dragonet, Atlantic wolfish and Scopthalmidae (turbots). It was not possible to identify one dermal denticles/tooth beyond the subclass (Elasmobranchii). Two ceratohyals deriving from the Atlantic horse mackerel were identified. In addition, one dentary belonging to the blackspot sea bream was present. This species has not been previously identified in Danish EBK or TRB fish bone assemblages, and also has a more southerly distribution. A right premaxilla deriving from a black sea bream was present within the assemblage. Similarly, this species has a more southerly distribution that is south of the English Channel (Enghoff *et al*. 2007). While a second vertebra could not be differentiated between two species (blackspot sea bream/black sea bream), it is additional evidence for a warmer climate during the Atlantic and Sub Boreal chronozones (Enghoff *et al*. 2007). Furthermore, one caudal vertebra deriving from a goldsinny-wrasse was identified whereas four vertebrae belonged to the greater weever. In total three dragonet vertebrae were identified. This

species had previously been identified in the fish bone assemblages from the coastal settlement at Asnæs Havnemark (Ritchie *et al*. 2013a) and the Norsminde kitchen midden (Enghoff 1989). Noteworthy was the presence of three wolfish teeth in the assemblage, another species that had not been previously identified.

Only six specimens deriving from species that reside in freshwater/brackish/marine environments were identified: European sea bass and thinlip grey mullet. Four specimens deriving from the European sea bass were identified. Presently this species has a more southerly distribution (Enghoff 2011). One specimen could be identified as a thinlip grey mullet, whereas a second could not be differentiated between the thicklip and thinlip grey mullets. The thinlip grey mullet has not been previously identified, but an unspecified grey mullet was present in the assemblage from the Kalvø kitchen midden (Enghoff 2011).

At least six species deriving from the Gobiidae family are known to occur in Danish coastal waters and some reside in freshwater (Brinkhuizen 2006). The one specimen in the assemblage could not be further identified to the lower genus and species level.

6.4.6. Size classes

At least 33 species from 27 families were represented in the material. Of these an estimation of TL was attempted for those specimens that were identified to the species level. It was not possible to establish TL for some of the specimens given the lack of comparative material in the reference collection. In Figure 6.6 the TL estimates are grouped according to size classes, and are presented by species. On the whole it can be seen that the majority of the species (n = 19) were represented by smaller individuals (15-30 cm). However, there were some, notably pike, roach, Atlantic cod, blackspot and black sea breams, mackerel, flounder and plaice that had a broad range in TL. The European eel represented the longest specimens in the material (ca. 70 cm).

6.4.7. European eel

Although caudal and thoracic vertebrae had been measured in a previous study (Robson *et al*. 2013), it is more than likely that the same individual had been represented more than

once, especially when the nature of the material is taken into consideration, that is to say the very subtle and thin layers of the column. Similarly, the numerous skeletal elements combined to produce the eel size-frequency diagrams for the kitchen middens at Bjørnsholm, Ertebølle, Nederst and Krabbesholm II (Enghoff 1986, 1991, 1994, 2011) probably reported the same individual more than once. In light of the above, the resulting size-frequency diagram (Figure 6.7) is based on measurements of 32 left ceratohyals (Table 6.6).

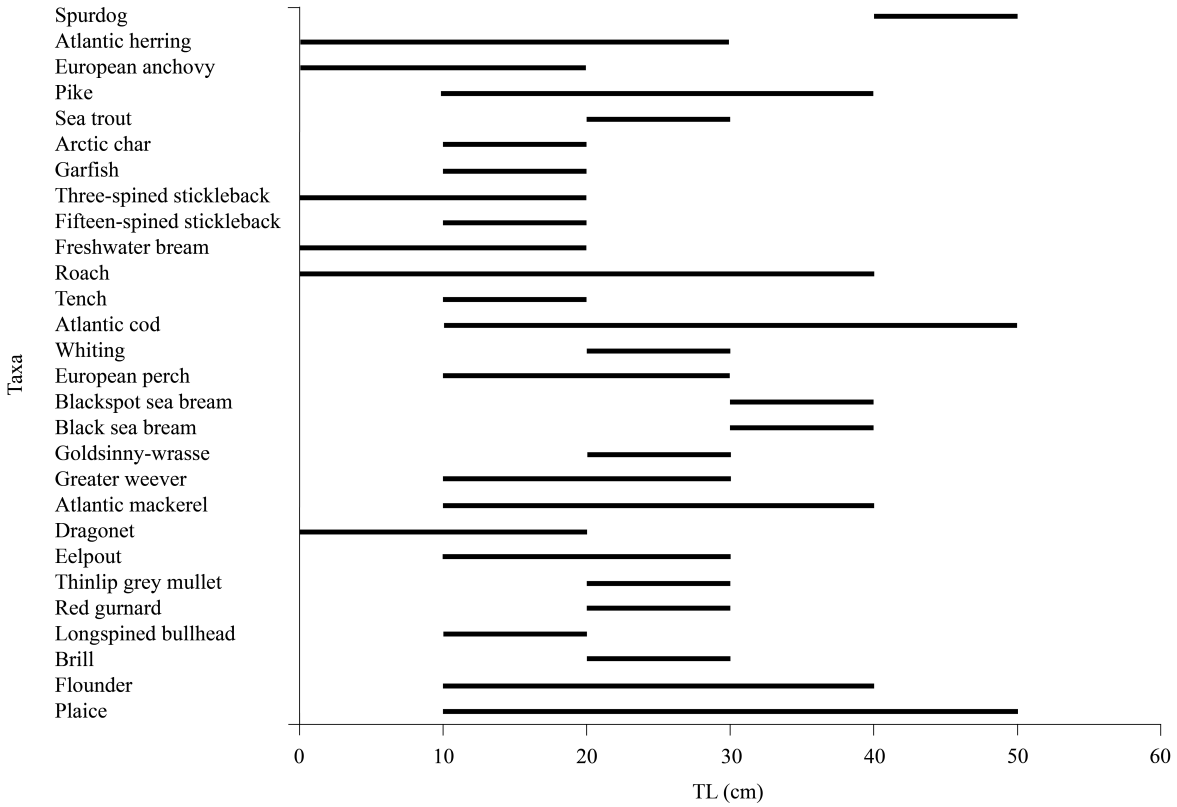


Figure 6.6: Size classes for 28 species of fish.

The data demonstrated that the majority of the eel at Havnø were medium sized (mean 46 cm, n = 32). The size frequency diagram shows that the eels ranged from 21 to 70 cm in TL. Estimates from the 32 eel ceratohyals from across the kitchen midden indicated that seven specimens representing individuals with a TL > 55 cm derived from females since males do not exceed this limit (Muus and Dahlstrøm 1964). In general, females are much larger, capable of attaining a maximum length of ca. 125-150 cm (Tesch 2003). On the other hand, males typically stay close to the coast and are retarded in growth (Pedersen

2013). The remaining size estimates indicate that 25 specimens could have belonged to either males or females.

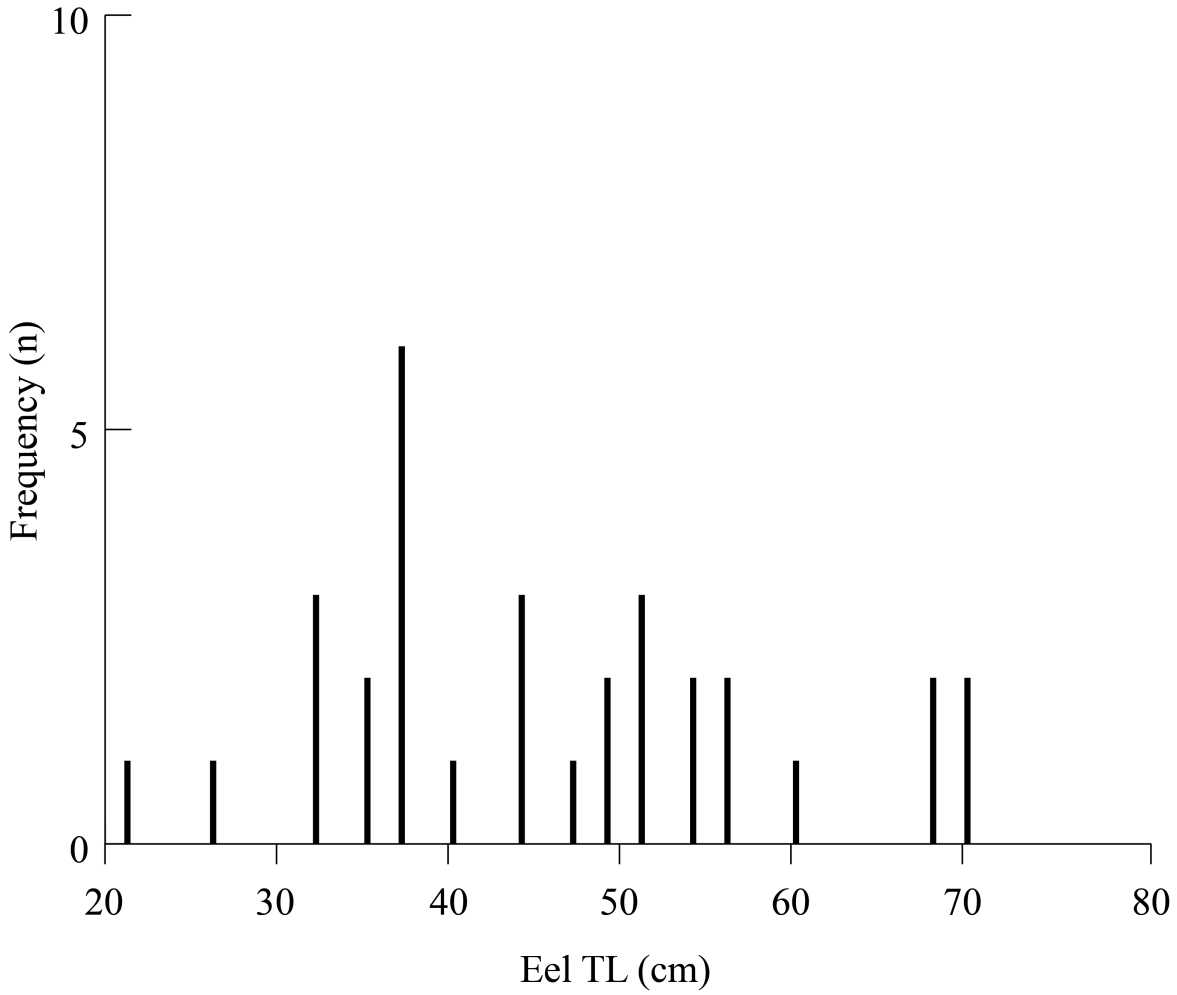


Figure 6.7: Eel size-frequency diagram.

Side/element	Right	Left	Indeterminate	Totals
Ceratohyal	24	34	8	66
Cleithrum	8	21	13	42
Dentary	12	20	8	40

Table 6.6: The measured skeletal elements to estimate TL.

In order to determine whether there was a difference in the size of the eels between the Mesolithic and the Neolithic, only those ceratohyals from contexts whereby the cultural epoch has been assigned have been included. Conservatively the dataset has been reduced

to 23 eel ceratohyals represented by both left and right elements. Inclusion was dependent upon the context of the hand-collected material, including those remains recovered during post excavation, or layer within the column samples. Likewise either the left or the right ceratohyal(s) was selected to reduce duplication. The resulting size-frequency diagram (Figures 6.8) is based on measurements of 19 left and four right ceratohyals. Of the 23 ceratohyals, 18 derived from contexts that have been dated to the EBK, one to the EBK-TRB transition, whereas the remainder to the TRB.

The data showed that EBK and TRB eel at Havnø were medium sized (mean 45 cm, n = 23). The EBK size-frequency diagram shows that eels ranged from 24 to 70 cm in TL (n = 18), whereas the size frequency diagram of eels from the TRB showed a size range from 32 to 49 (n = 4). The one eel deriving from a transitional context had an estimated TL of 37 cm. The mean TL of the EBK eel was ca. 48 cm (n = 18) whereas the mean TL of those eels from the TRB was ca. 37 cm. While it could be argued that these data demonstrated a change in TL across the Mesolithic-Neolithic transition, the sample set is too small to be significant.

6.4.8. Atlantic cod

The resulting size-frequency diagram (Figure 6.9) is based on measurements of nine first vertebrae. The data showed that the majority of the cod at Havnø were small (mean 22 cm, n = 9). The size frequency diagram shows that the cods ranged from 12 to 34 cm in total length.

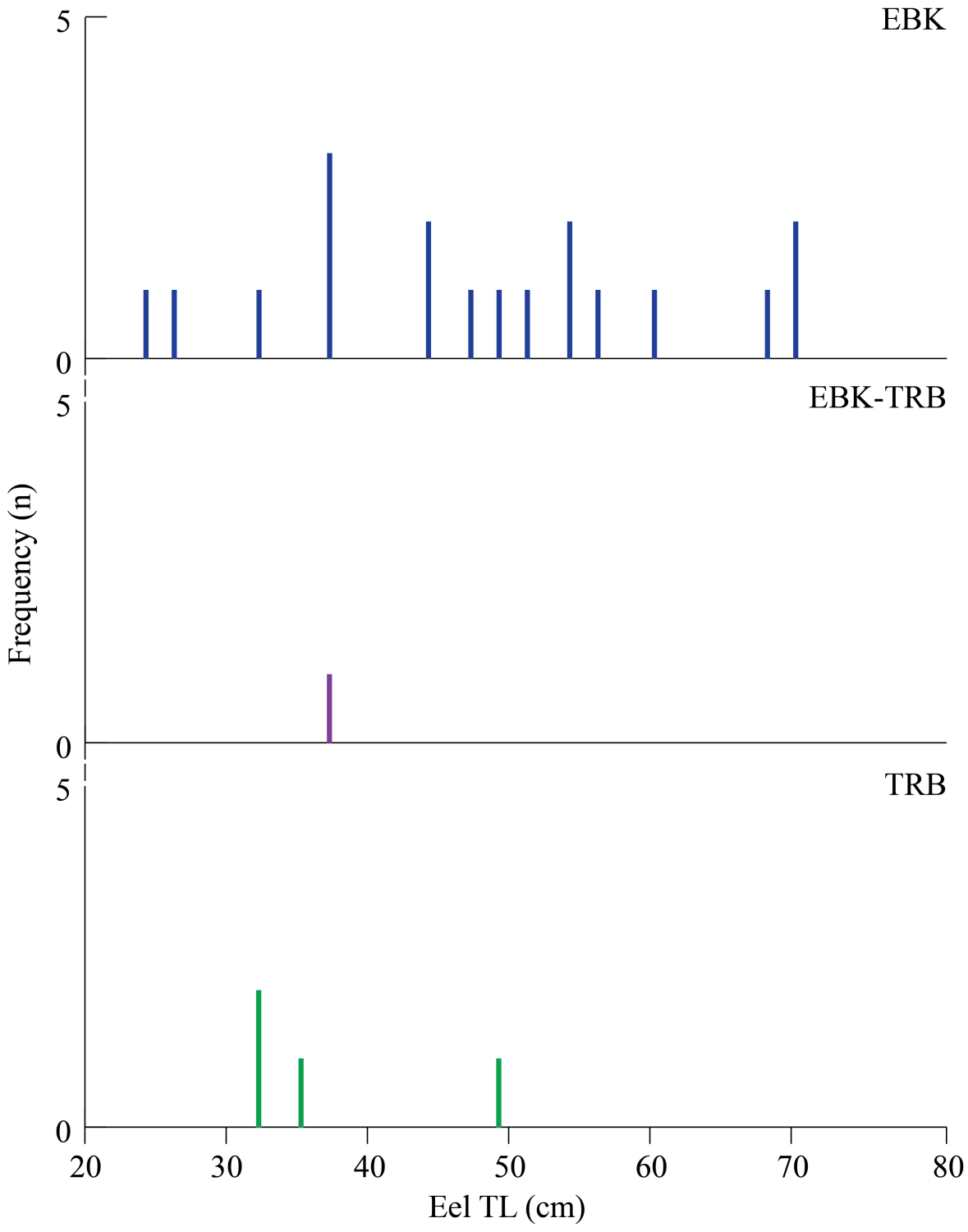


Figure 6.8: Eel size-frequency diagrams disaggregated according to cultural epoch.

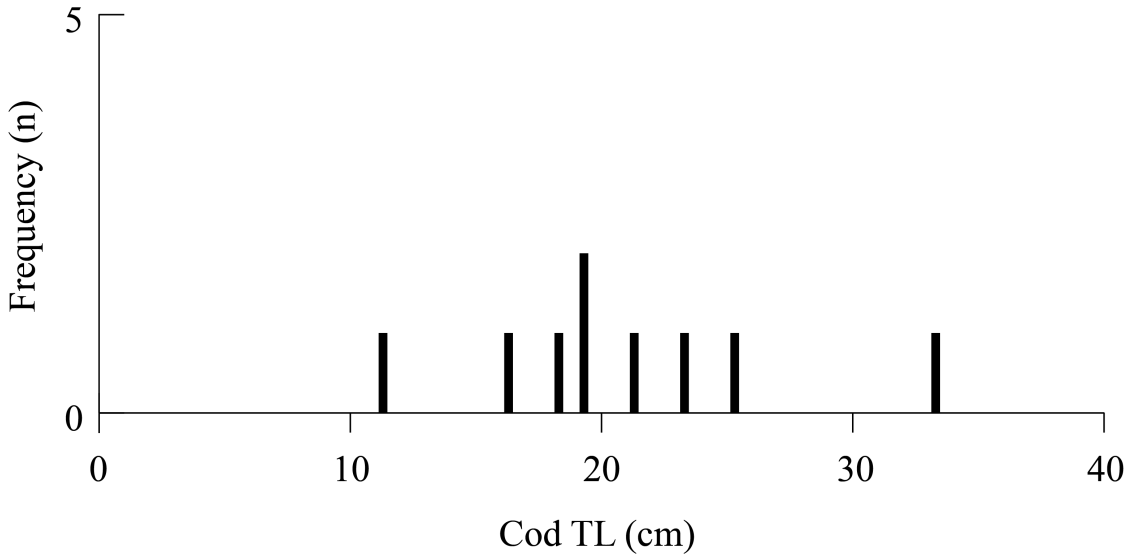


Figure 6.9: Cod size-frequency diagram.

6.4.9. Taphonomy

In general, the fish remains were very well preserved, although haemal and neural spines as well as similar projections were often absent or broken. This situation is similar to other contemporaneous fish bone assemblages from Denmark (Enghoff 1986, 1989, 1991, 2011). The material most likely represented refuse from meals that were discarded along with other anthropogenic material. Elements from the head, shoulder and pelvic girdles, vertebral column and other skeletal elements, including fins, were present. In addition, dermal structures as well as scales were recovered, but otoliths were absent. Moreover, individual species have different frequencies of elements (Casteel 1976; Schmölcke and Ritchie 2010) as well as differential rates of degradation (Enghoff 1986; Enghoff *et al*. 2007). For instance, eel, herring, salmon and flatfish tissue is, in general, lipid rich, and its decomposition may accelerate the structural decay of their elements when compared to non-oily fish (Enghoff 1986, 2011; Lepiksaar and Heinrich 1977; O'Connor 2008; Wheeler and Jones 2009). Despite these taphonomic processes, eel bones predominate which implies that they were probably an important resource at the kitchen midden.

6.4.10. Pre-depositional processes

6.4.10.1. Traces of burning

Although several hearths have been excavated across the kitchen midden, of the 2,675 identified specimens, only 60 fish bones (2.2%) showed evidence of having been burnt (Table 6.7). While the colour was recorded, it cannot necessarily be used to deduce the type of fire or the temperature reached since it is dependent upon a number of factors including the position of the remains in the fire and the degree of exposure (Nicholson 1995). In addition, different elements vary in colour due to the duration of heat exposure, size and type of element as well as the local atmospheric environment (Nicholson 1995). However, 13 remains were calcined (grey or white in colour) and probably derived from the centre of an intentional fire (Nicholson 1995).

Colour	**Frequency**
Black	27
Burnt	1
Dark brown	10
Dark brown/black	4
Dark brown/red	2
Dark grey/brown	6
Light brown/white	1
Sandy brown/black	3
White	6
Totals	**60**

Table 6.7: Frequency of specimens showing traces of having been burnt.

6.4.10.2. Vertebrae showing metabolic distortion

When a mammal consumes a complete fish its skeletal elements may become distorted or flattened during their passage through the gastrointestinal tract (Wheeler and Jones 2009). These effects were identified on vertebrae and termed ‘metabolic distortion’ by Beerenhout (1996).

At Havnø, 1,787 vertebrae were identified. Of these seven (0.4%) showed evidence of

metabolic distortion. Four of the vertebrae derived from European eel, one unidentified Pleuronectidae, one flounder and one vertebra that could not be identified. Three of these were recovered from two column samples and would probably not have been recovered had dry screening with fine meshes been carried out. Their presence indicates that they could have been consumed by humans or commensal animals (Jones 1984, 1986; Nicholson 1993).

6.4.10.3. Traces of gnawing

One left eel subopercular showed evidence of having been gnawed. The marks observed were almost certainly made by a micro-mammal.

6.4.11. Post-depositional processes

Given the complex stratigraphy of shell middens themselves, identifying the processes from deposition to recovery was extremely difficult. However, there are a number of methods that can be applied in order to determine the degree of the post-depositional effects on the material itself, for example the amount of taphonomic loss (Aaris-Sørensen 1983). Despite differences between skeletal element and species (Lepiksaar and Heinrich 1977), the post depositional effects within the shell matrices have likely to have had an impact on the fish remains.

During the excavation of layer VI of column AFAA it was noted that there was a absence of fish remains. This may be due to the taphonomic processes present, for instance the overlying weight of the shell matrices and/or rainwater percolation. In addition, there was an absence of fish remains from layers I and II in column AFCF. Likewise this could have been the result of either weight, or percolation, or perhaps even disturbance or localized events that have not been conducive to preservation. It is also possible that the younger deposits, those dating to the Neolithic, and higher up in the midden sequence, may have been hindered by their position. Such a situation was evident at the Norsminde kitchen midden where only one fish bone was recovered from the Neolithic layers despite the intensive employment of screening during the excavations (Enghoff 1989). In general the shell matrices create optimal conditions for the preservation of organic materials (Noe-

Nygaard 1987).

6.4.11.1. Absence of otoliths versus presence of scales

Although over 10,000 fish remains were recovered throughout the course of the excavations at the kitchen midden, there was a dearth of otoliths. In comparison, a total of 16 scales were recovered from both hand collection and column sampling. Moreover, numerous otoliths were recovered from the kitchen middens at Bjørnsholm and Ertebølle (Enghoff 1986, 1991; Froom 1979) as well as the coastal site Asnæs Havnemark (Ritchie *et al*. 2013a) and the shell-bearing deposits at Dragsholm (Ritchie 2010).

While their absence may be partly attributed to conditions not conducive to preservation, or the inconsistency of sieving, the most likely explanation is their size. In general, when the remains of larger Gadidae are recovered, so are their otoliths (Ritchie *et al*. 2013a). However, the Havnø assemblage was predominantly composed of specimens derived from smaller fish. In addition, since there is a lack of organic material within the otolith matrix, their structural integrity is prone to decomposition by microorganisms (Nicholson 1996). It seems unlikely that they were not recognized in the field since the same excavation team has been working under Søren H. Andersen since the 1970s.

6.4.12. Representativeness of the samples and identifications

6.4.12.1. Hand collected material versus column samples

Of the 2,675 identified fish remains, the majority (55.0%, NISP = 1,471) derived from the hand-collected material. In general the material provides a very biased impression of the identified fish remains (Figure 6.10). The assemblage is dominated by the European eel (50.1%, NISP = 737). This is followed by the remains of species that grow large, including Gadidae (17.3%, NISP = 254) and flatfish (12.0%, NISP = 177). In general smaller specimens are underrepresented. However noteworthy are the remains of Clupeidae (7.3%, NISP = 107) and Gasterosteidae (2.8%, NISP = 41) that are well represented despite their size as well as the remains of wolfish, bullhead, elasmobranchii, anchovy, pike, sticklebacks, perciformes and eelpout. This is likely the result of the post excavation

processing of the bulk and soil samples that have been included as well as isolated single depositional events within the kitchen midden that were encountered.

The identified fish remains that were recovered from the six column samples constituted the remainder of the assemblage (45.5%, NISP = 1,204) and provide a more realistic impression of the species spectrum that was consumed (Figure 6.11). Likewise the assemblage is dominated by the European eel (75.2%, NISP = 905) and is probably attributable to the fact that the European eel possesses more vertebrae than the other identified taxa. Similarly this was followed by flatfish (8.7%, NISP = 105) and Gadidae (6.3%, NISP = 76). Numerous smaller specimens derived from smaller species of fish were also recovered, for instance sand eel, dragonet, gobies, goldsinny-wrasse, mullets and sea robins, since smaller mesh sizes were utilised (Figure 6.11).

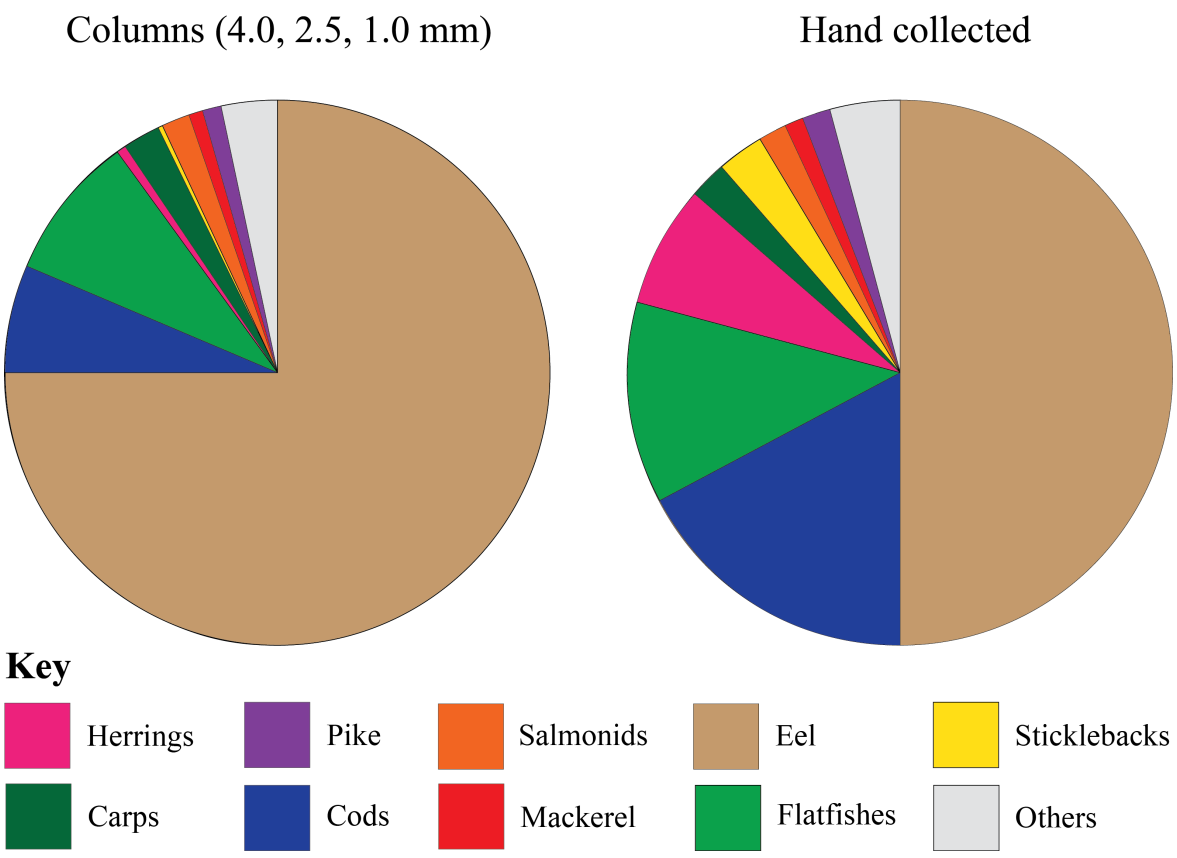


Figure 6.10: Species composition of the assemblage of fish remains recovered by hand and by the systematic excavation of six column samples.

6.4.12.2. Differences in context and deposition

The remains were recovered from numerous grid squares and will probably represent the inhabitant's different fishing practices across time. However since the data are grouped according to recovery method they may represent time-averaged years. One way to elucidate temporal and spatial variation is to disaggregate the material per layer for the six columns.

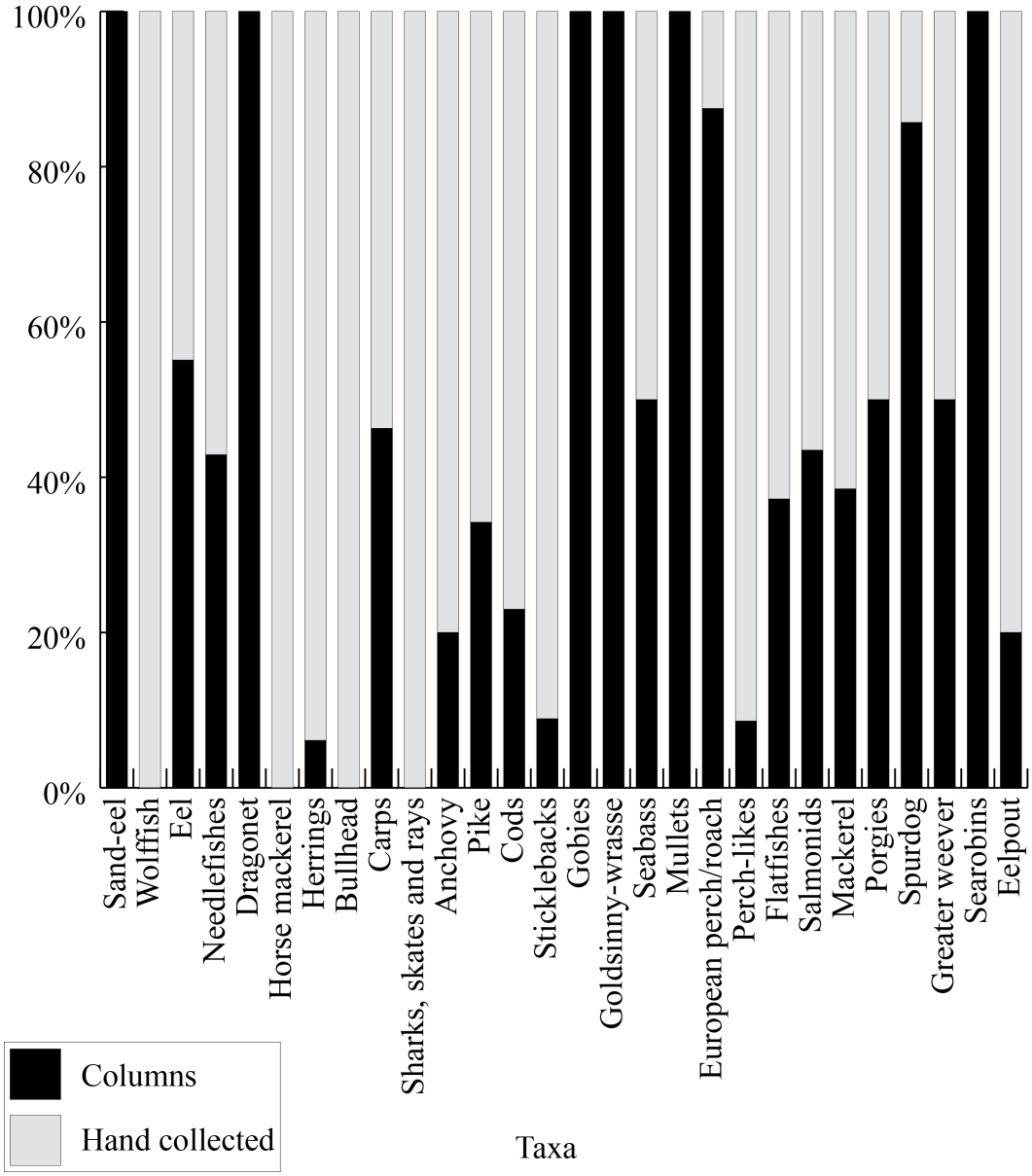


Figure 6.11: Species compositions of the hand collected and columns demonstrating the recovery of smaller species of fish.

6.4.12.3. Distribution of fish remains within the column samples

To assess temporal variability the material has been grouped according to location (Figure 6.12 and Table 6.8). Group one includes columns ACAA and YAA (Robson *et al*. 2013). Group two included only the one column (ACDD). Group three included the two columns that were situated two meters to the north of group two (AFDC and AFCF). Columns AFAA and AFBE represented group four.

Group	**Group one**		**Com.**	**Group two**	**Group three**		**Com.**	**Group four**		**Com.**
Layer	**ACAA**	**YAA**		**ACDD**	**AFCF**	**AFDC**		**AFAA**	**AFBE**	
Clean					3		3			
1	1	45	46					2	1	3
2	2	52	54	59		47	47	22	1	23
3	34	95	129	49	10	36	46	30	25	55
4	88	53	141	22	26	7	33	21	15	36
5	148	39	187	13	25	14	39	22	27	49
6	254	12	266	13	14	32	46		3	3
7	76	2	78	12	5	17	22		- - - -	
8	21	6	27	- - - - - -	- - - -	- - - - -	- - - -	- - - - -		- - - - -
9	6	2	8							
10	1		1							
NISP	**631**	**306**	**937**	**168**	**83**	**153**	**236**	**97**	**72**	**169**

Table 6.8: Distribution of the fish remains in the seven column samples by layer. The dotted lines demarcate that there were no additional layers in this column/group (Robson et al. 2013). Key: cleaning, clean., combined total of samples within group, com.

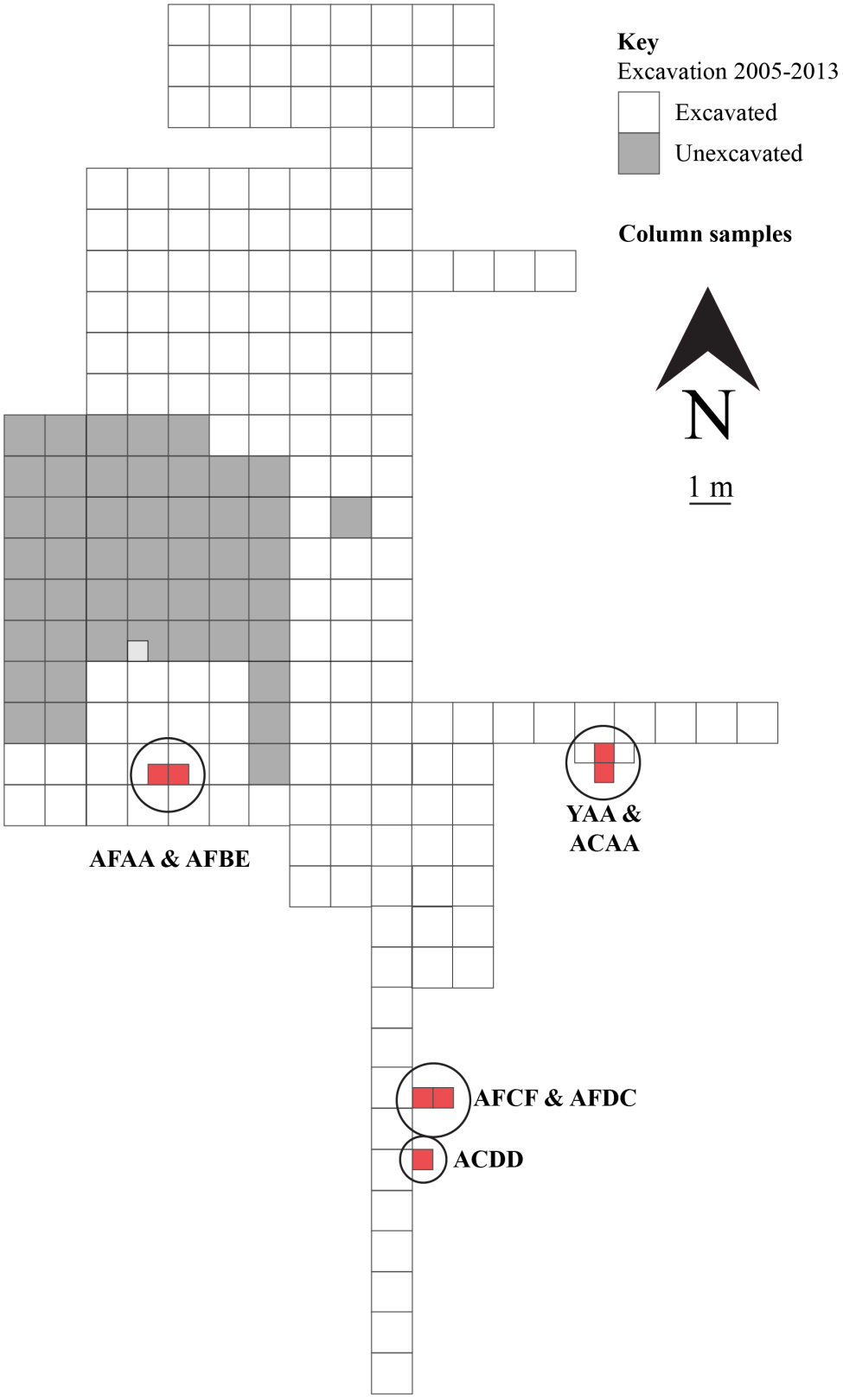


Figure 6.12: The full extent of the Havnø excavations and the grouped column sample locations in this study, including YAA (Robson 2011).

In general the fish remains did not have a uniform horizontal and vertical distribution. It is likely that the differences in the frequency of identified fish remains is not a reflection of the recovery methods since four of the columns were excavated by the author who also oversaw the excavations of the other three that were undertaken by the same volunteer. Consequently the material is probably a reflection of the thickness of the midden sequence and differential preservation across the site. The thickest shell deposits were encountered in the midden proper and it is from this area where the most fish remains were recovered and identified (columns ACAA and YAA). In total 1,792 fish remains were recovered and of these 937 could be identified (52.3%). This was followed by columns AFAA and AFBE that were excavated to the west of the 1894 trench. Despite the fact that the deposits of the midden proper were thinnest in this area no less than 664 specimens were recovered, although only 169 could be identified (25.5%). This was followed by column ACDD that was excavated from the most southerly location in the kitchen midden. From this column 619 specimens were recovered, and only 168 could be identified (27.0%). Two meters to the north of column ACDD, columns AFCF and AFDC were excavated and were adjacent to one another. A total of 519 fish remains were recovered from these two columns and 236 could be identified (45.5%). Since this area had been heavily disturbed it is not surprising that the least specimens were recovered. To assess spatial and temporal variability the fish species compositions for the six columns are presented.

6.4.12.4. The species composition of the columns

The greatest spectrum of species was identified in the area with the thickest shell deposits. In total 631 specimens were identified in column ACAA. Although European eel dominated, 15 other taxa were identified (Figure 6.13). There was a uniform distribution of species from layers III to VI. The spectrum of species was most varied in layer VII and was represented by 12 taxa. In layers I, II, IX and X only one taxon was identified.

In column ACDD a total of 168 fish remains were identified. Again European eel dominated although 13 other taxa were identified (Figure 6.14). Except for layer III, there was a uniform distribution of species in layers II to VI. Layer II had the most variability (*n* = 9), whereas layer VII was equally split between European eel and perch/roach.

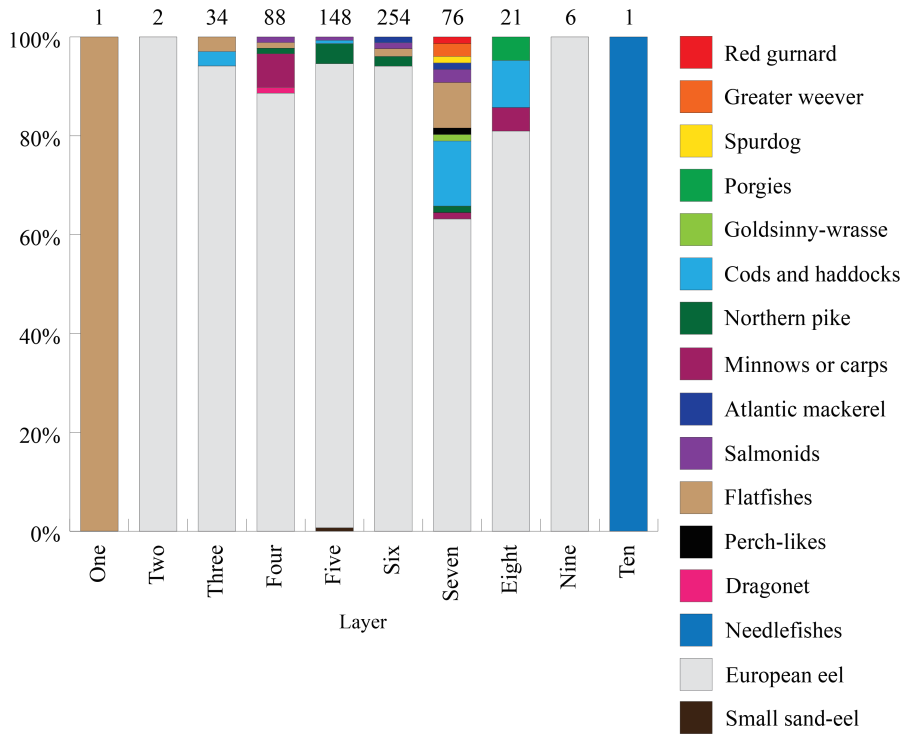


Figure 6.13: Species composition of column ACAA with NISP values above each bar.

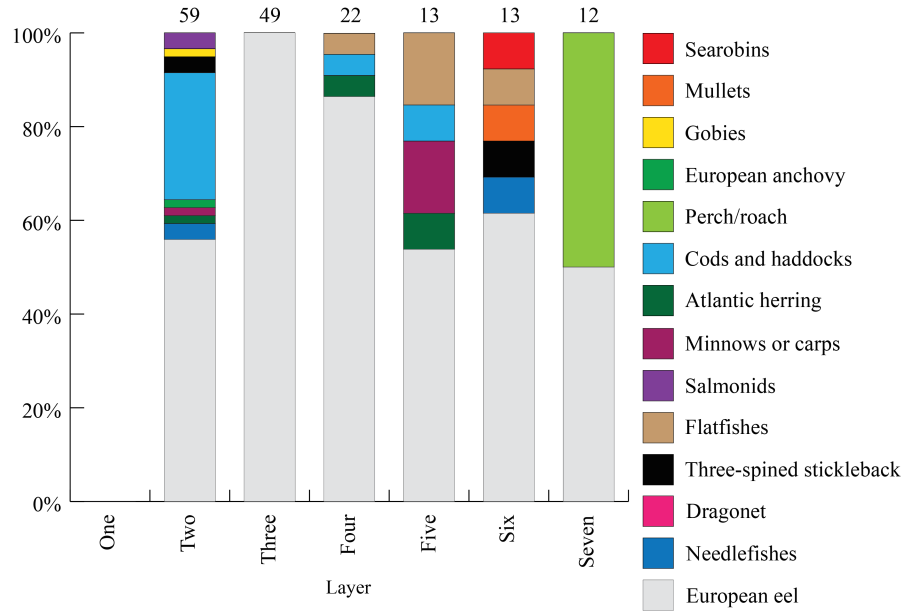


Figure 6.14: Species composition of column ACDD with NISP values above each bar.

In total 83 fish remains were identified from column AFCF. In layer III European eel and flatfish were equally represented (Figure 6.15). There was a uniform distribution of species

from layers IV to VI. European eel dominated these layers, whereas Gadidae dominated layer VII. In general only smaller specimens of species that grow larger were encountered.

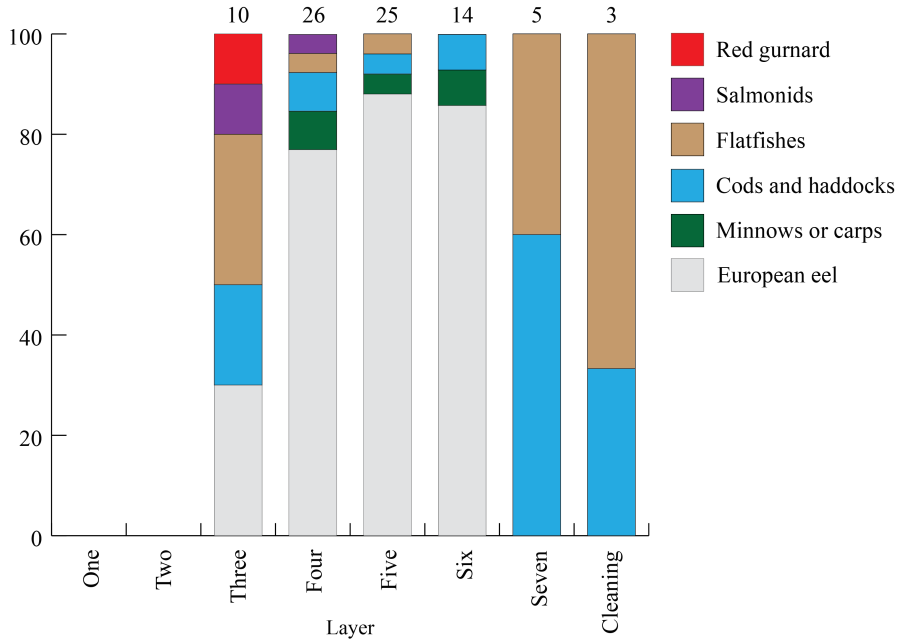


Figure 6.15: Species composition of column AFCF with NISP values above each bar.

In column AFDC a total of 153 fish remains were identified. Similarly there was a uniform distribution of species in layers II and III (Figure 6.16). In layers IV and V only four and three taxa were identified respectively. Overall the impression was similar to column AFCF with European eel dominating although Gadidae and flatfish were identified in relative frequencies. Despite the fact that both columns were situated next to one another, AFDC had a greater species spectrum that also included the remains of smaller species including the eelpout, herring and three-spined stickleback.

In column AFAA 97 fish remains were identified. The assemblage comprised of the specimens from layers I to V (Figure 6.17). Layer I was solely comprised of flatfish, whereas European eel and Gadidae dominated layers II and III respectively. Layer IV was predominantly composed of the European eel, while flatfish dominated layer V. Other taxa were present less frequently. Of the six columns, AFAA had the most temporal variability.

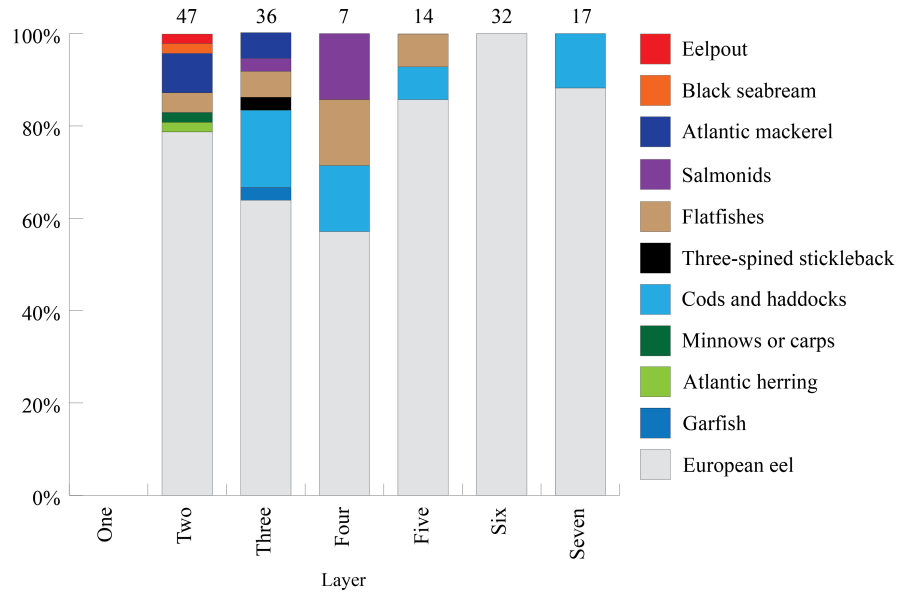


Figure 6.16: Species composition of column AFDC with NISP values above each bar.

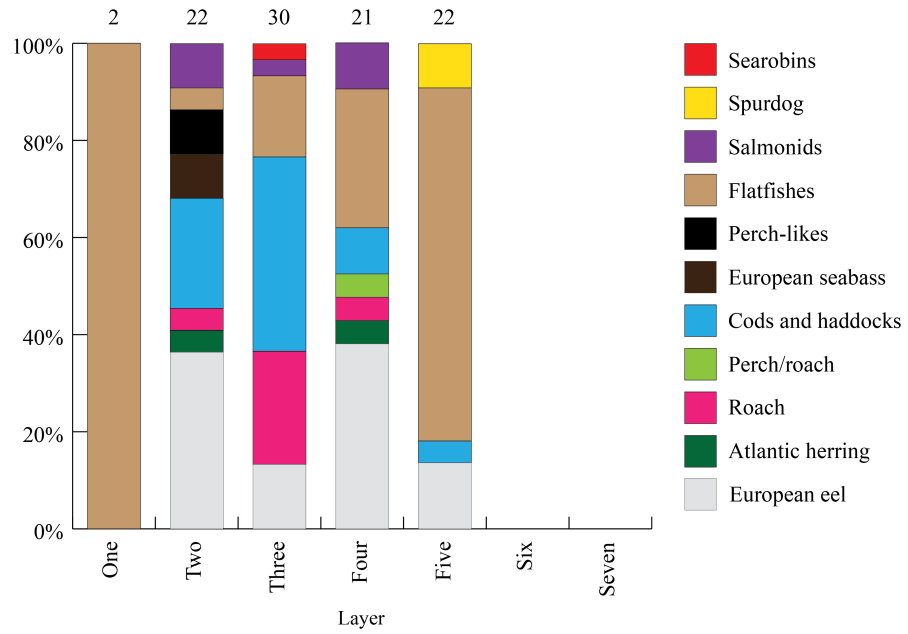


Figure 6.17: Species composition of column AFAA with NISP values above each bar.

In total 72 fish remains were identified in column AFBE (Figure 6.18). The species spectrum was very similar to the adjacent column (AFAA). Layers I and II were solely comprised of migratory species. Layer III was predominantly composed of flatfish, whereas Gadidae and spurdog were equally represented in layer IV. In layers V and VI the flatfishes

dominated. Spurdog were only identified in the lower layers (IV and V) of this column.

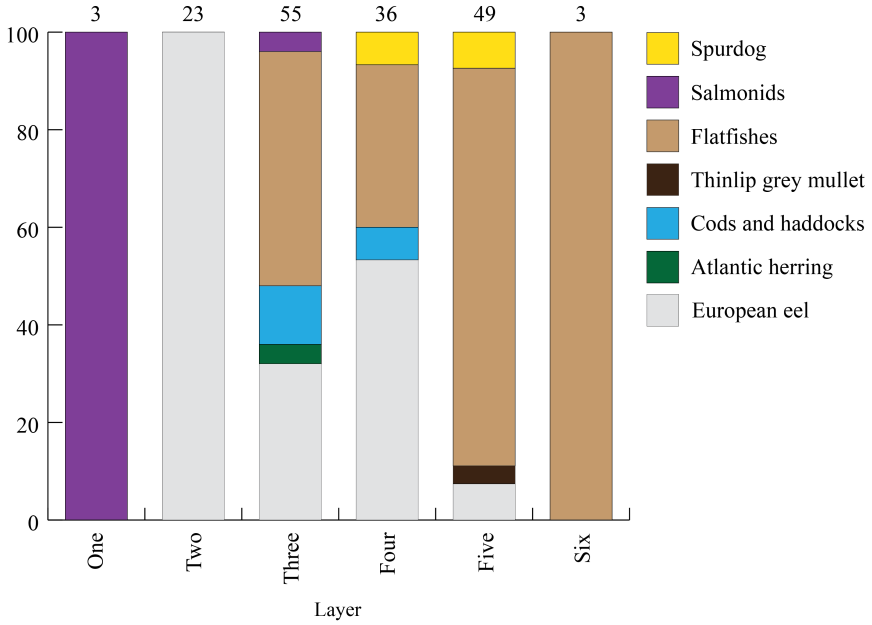


Figure 6.18: Species composition of column AFBE with NISP values above each bar.

6.4.12.5. Temporal change within the columns

To assess temporal change the layers have been grouped according to period. Of the 631 identified specimens from column ACAA, 628 were derived from the EBK layers, thus comparison is invalid. However, column YAA that was excavated from the adjacent square demonstrated that fishing for the European eel, three-spined stickleback, Gadidae and flatfish continued across the Mesolithic-Neolithic transition (Robson *et al*. 2013).

Eighty-three specimens were identified from column AFCF. Of these, 44 were recovered from the EBK layers, and 36 derived from the Neolithic layers. Furthermore, three specimens were recovered during section cleaning. In this column fishing during the EBK was chiefly directed towards the European eel, which was followed by Gadidae, flatfish and Cyprinidae. During the Neolithic European eel fishing continued. This species dominated and was followed by Gadidae and flatfish.

Of the 153 identified fish remains from column AFDC, 63 were recovered from the EBK

layers, and 90 derived from the Neolithic layers. The European eel dominated the EBK layers. This species was followed by Gadidae and flatfish. This column had the largest assemblage dating to the Neolithic from across the kitchen midden, and demonstrated that the European eel continued to be exploited across the EBK-TRB transition. This was followed by Gadidae, mackerel and flatfish. Two specimens belonged to Salmonidae, and an additional six taxa were represented by one specimen each.

Ninety-seven fish remains were identified from column AFAA. Of these, 43 were recovered from the EBK layers, and 24 derived from the Neolithic layers. In addition thirty specimens belonged to the EBK-TRB transitional layer. During the EBK flatfish dominated, followed by European eel, Gadidae, spurdog and Salmonidae. Three further taxa were identified. On the other hand European eel dominated the Neolithic layers. This species was followed by Gadidae and flatfish. Eight further specimens deriving from five taxa were also identified.

Of the 72 identified fish remains from column AFBE, 45 were recovered from the EBK layers, and two were derived from the Neolithic layers. In addition, 25 belonged to the EBK-TRB transitional layer. The species spectrum for the EBK layers was broadly similar to column AFAA, which is not surprising since they were situated next to one another. Flatfish dominated, which was followed by European eel and spurdog. Gadidae and thinlip grey mullet were represented by one specimen each. During the Neolithic Salmonidae and European continued to be exploited and were represented by only one specimen each.

6.5. Discussion

6.5.1. Introduction

The inhabitants of the Havnø kitchen midden caught fish – especially the catadromous European eel, the chiefly marine Gadidae, and flatfish (Pleuronectidae/Scopthalmidae) – the latter occurring in both brackish and marine environments. They also consumed freshwater (mainly Cyprinidae) and anadromous taxa (Salmonidae and Gasterosteidae), even in the later occupation phase, by which time the local environment was probably

dominated by brackish conditions. This implies that the occupants purposely continued exploiting the estuarine environment of the Mariager Fjord. The numerous remains of young Clupeidae probably reflect incidental marine ingressions (Brinkhuizen 2006). Despite the preponderance of European eel remains that could have been caught in the freshwater environment, the carbon and nitrogen stable isotope analysis demonstrated a population associated with marine-residency (Robson *et al*. 2012). The presence of Cyprinidae, Esocidae, Cottidae and Percidae in small quantities implies fishing in a freshwater environment and transportation to the island, although several of these species may also have been caught in the estuary.

6.5.2. Inter-site variability

6.5.2.1. Introduction

To assess inter-site variability, available fish remains from a further three contemporaneous kitchen middens have been analysed (Figure 6.19). A description of the samples that were analysed is presented in Appendix 5. The following section provides a short summary of the results for each site.

6.5.2.2. Krabbesholm II

The fish taxa identified from the column sample are listed in Table 6.9. A total of 830 fish remains were identified in this study. Of these, 640 could be identified to the species or family level. Eleven fish families were represented. Vertebrae constituted 86.0% (NISP = 550) of the assemblage with 14.0% (NISP = 90) consisting of cranial and other skeletal elements. The data (Table 6.9) are based on those fish remains that were identified to the species or family level. The assemblage has been divided according to culture.

The fish remains were comparable with the material from Havnø. Similarly they were very well preserved although spines and other projections were often absent or incomplete. Elements from the head, shoulder and pelvic girdles, vertebral column and other skeletal elements, including fins, were present. There was no evidence of pre-depositional processes, while the post depositional processes will be discussed below.

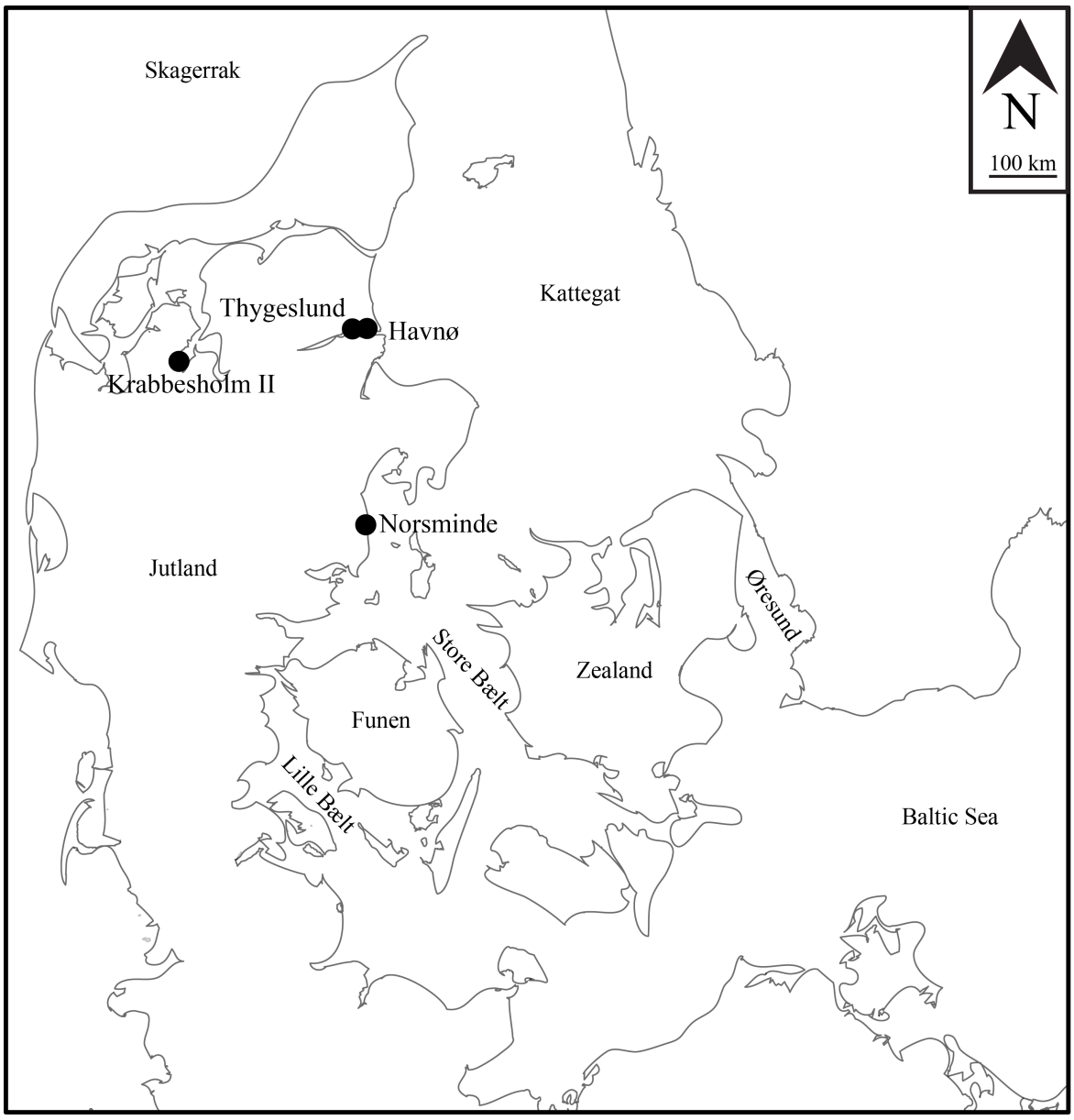


Figure 6.19: Map of Denmark showing the locations of the four kitchen middens that were analysed in this study.

Fish species from 11 families were represented in the material. Of the 640 identified specimens, the majority are derived from the EBK layer, whereas only 10 specimens were identified from the TRB layers. The EBK assemblage was dominated by the European eel, which was followed by the Atlantic herring, three-spined stickleback, Cyprinidae, Pleuronectidae, Atlantic mackerel, and European anchovy. In addition, seven taxa were identified. The European eel dominated the TRB assemblage, and was followed by one

specimen derived from Atlantic herring, Gadidae and European perch respectively. Since only three of the layers were sampled it was not possible to assess the distribution of the fish remains within the column. However, previous analysis has demonstrated that there is a general paucity of fish remains in the Neolithic layers (NISP = 64), whereas they are more frequent in the EBK layer (NISP = 369), and best represented in the transitional layer (NISP = 2,706) (Enghoff 2011).

Taxon	**EBK**		**TRB**	
	NISP	**%**	**NISP**	**%**
Spurdog	1	0.2		
Clupeidae	1	0.2		
Atlantic herring	85	13.5	1	10
European anchovy	11	1.7		
Salmonidae	1	0.2		
European eel	451	71.6	7	70
Garfish	1	0.2		
Three-spined stickleback	25	4.0		
Cyprinidae	18	2.9		
Gadidae	7	1.1	1	10
Percidae	2	0.3		
European perch			1	10
Atlantic mackerel	12	1.9		
Scopthalmidae/Pleuronectidae	1	0.2		
Pleuronectidae	14	2.2		
Totals	**630**	**100**	**10**	**100**

Table 6.9: Identified fish in the column with quantification.

The majority of the fish species in the material were represented by smaller individuals (15 and 30 cm). The TL of the spurdog ranged from 40 to 50 cm, while Atlantic herring measured between 1 and 30 cm. The estimates for the European anchovy specimens were from 1 to 20 cm, whereas the one Salmonidae specimen ranged between 1 and 20 cm. Based on the measurements of eight left European eel ceratohyals (Enghoff 1986) the specimens deposited at the Krabbesholm II kitchen midden measured between 21 and 58 cm. One garfish specimen measured between 20 and 30 cm, whereas the three-spined

stickleback individuals were less than 20 cm. The Cyprinidae measured between 1 and 30 cm, while the Gadidae ranged from 1 to 40 cm. The Percidae and European perch specimens were less than 20 cm, while the Atlantic mackerel measured between 20 and 40 cm. The flatfish measured between 1 and 60 cm.

6.5.2.3. Norsminde

The fish taxa identified from layer X are listed in Table 6.10. A total of 126 fish remains were identified. Of these, 75 could be identified to the species or family level. Five fish families were represented. Vertebrae constituted 78.7% (NISP = 59) of the assemblage with 21.3% (NISP = 16) consisting of cranial and other skeletal elements. The data (Table 6.10) are based on those fish remains that were identified to the species or family level. The assemblage is dated to the EBK.

Taxon	**NISP**	**%**
Atlantic herring	2	2.7
European eel	39	52.0
Three-spined stickleback	1	1.3
Gadidae	32	42.7
Shorthorn sculpin	1	1.3
Totals	**75**	**100.0**

Table 6.10: Identified fish in the column with quantification.

In general, the fish remains were very well preserved although spines and similar projections were often absent. Elements from the head, shoulder and pelvic girdles, vertebral column and other skeletal elements, including fins, were present. Only nine specimens had traces of having been burnt, and all were black in colour.

Fish species from five families were represented in the material. European eel dominated the assemblage, which was followed by Gadidae and Atlantic herring. The three-spined stickleback and shorthorn sculpin were represented by one specimen each. It is not possible to assess the distribution of the fish remains within the column or temporal change at the kitchen midden from this assemblage alone.

The majority of the fish species in the material were represented by smaller individuals (15 and 30 cm). The TL of the Atlantic herring was less than 20 cm. Based on the measurements of two ceratohyals (right and left) and one dentary (Enghoff 1986) the European eel measured between 25 and 42 cm. Since the size estimates were appreciably different they probably derived from at least three individual specimens. The Gadidae ranged from 10 to 40 cm, whereas the three-spined stickleback was less than 20 cm. The one shorthorn sculpin was similarly less than 20 cm.

6.5.2.4. Thygeslund

The fish taxa identified from the Thygeslund kitchen midden are listed in Table 6.11. A total of 3,154 fish remains were identified. Of these, 631 could be identified to the species or family level. At least 16 fish families were represented. Vertebrae constituted 60.2% (NISP = 380) of the assemblage with 39.8% (NISP = 251) consisting of cranial and other skeletal elements. The data (Table 6.11) are based on those fish remains that were identified to the species or family level.

In general, the fish remains were very well preserved although spines and similar projections were often absent. Elements from the head, shoulder and pelvic girdles, vertebral column and other skeletal elements, including fins, were present. In total five specimens had tentative traces of butchering, for example a vertebra that was broken transversely. Since there were relatively few specimens, it was unclear whether or not the fish were processed at the kitchen midden. Three vertebrae showed evidence of metabolic distortion, and could have been consumed by humans or commensal animals (Jones 1984, 1986; Nicholson 1993).

Fish species from 16 families were represented in the material. Three-spined stickleback dominated the assemblage, which was followed by the European eel and greater weever. These were followed by Pleuronectidae, Gadidae, Salmonidae, and Atlantic mackerel. In addition, 15 taxa were identified. Although the assemblage has been dated to the EBK and TRB cultures, an on-going course of AMS radiocarbon dating will help to elucidate the degree of temporal change at the kitchen midden.

Taxon	**NISP**	**%**
Clupeidae	17	2.7
Atlantic herring	13	2.1
Northern pike	1	0.2
Salmonidae	38	6.0
Sea trout	1	0.2
European eel	129	20.4
Garfish	2	0.3
Three-spined stickleback	129	20.4
Cyprinidae	18	2.9
Roach	1	0.2
Gadidae	39	6.2
Atlantic cod	2	0.3
European perch	1	0.2
European sea bass	1	0.2
Greater weever	125	19.8
Atlantic mackerel	27	4.3
Thinlip grey mullet	1	0.2
Red gurnard	1	0.2
Shorthorn sculpin	7	1.1
Scopthalmidae/Pleuronectidae	3	0.5
Pleuronectidae	71	11.3
European flounder	4	0.6
Totals	**631**	100.0

Table 6.11: Identified fish in the column with quantification.

The species spectrum comprised of both marine and to a lesser extent freshwater fish. However, the majority migrate between the two ecotones. At least two anadromous species of fish were identified in the material: sea trout and three-spined stickleback. Two of the identified species of fish are catadromous: European eel and European flounder. Atlantic herring, garfish, Atlantic cod, Atlantic mackerel and red gurnard represented marine fish that are able to tolerate brackish to freshwater throughout their life histories. Four freshwater fish that can reside in weakly brackish waters were identified: pike, roach, perch and shorthorn sculpin. The greater weever represented the only chiefly marine species in the assemblage, whereas two specimens deriving from species that reside in

freshwater/brackish/marine environments were identified: European sea bass and thinlip grey mullet.

The majority of the fish species in the material were represented by smaller individuals (15 and 30 cm). The TL of the Clupeidae was in general less than 20 cm although one specimen was approximately 40 cm. Similarly the Atlantic herring were less than 30 cm. The one pike specimen was less than 30 cm, whereas the Salmonidae and sea trout ranged from 1 to 50 cm. Based on the measurements (Enghoff 1986) of two ceratohyals (right and left), three right cleithra and three dentaries (one right and two left), the European eel measured between 27 and 82 cm. Since the size estimates were appreciably different they probably derived from at least eight individual specimens. The three-spined sticklebacks were less than 20 cm, whereas the Cyprinidae and roach ranged from 10 to 40 cm. The Gadidae including Atlantic cod measured between 10 and 50 cm, while the one European perch specimen was less than 30 cm. The one European sea bass individual was less than 10 cm, whereas the greater weever ranged from 10 to 40 cm. The mackerel individuals measured between 10 and 50 cm, while the thinlip grey mullet and red gurnard measured between 20 and 30 cm. The shorthorn sculpin measured between 10 and 30 cm, and the flatfish including flounder ranged from 10 to 40 cm.

6.5.3. Fish taxa not previously identified

In total five species, including Arctic char, blackspot sea bream, Atlantic wolfish, thinlip grey mullet and red gurnard (Figure 6.20) were present in the Havnø, and Thygeslund assemblages. These taxa had not been previously identified. The presence of Arctic char is significant because the species has a European distribution that ranges from the northern Atlantic southward to southern Norway as well as Iceland and southern Greenland. In addition, there are a number of isolated populations in the northern UK, Scandinavia, Finland and the Alps (Whitehead *et al*. 1989). Blackspot seabream and Atlantic wolfish are presently distributed in the eastern Atlantic, but the latter has been identified in the North Sea, along the Scandinavian coasts as well as the Baltic Sea (Muus and Dahlstrøm 1964). Thinlip grey mullet and red gurnard are currently absent from Danish waters possessing a more southerly and easterly distribution throughout Europe. They fall into the category of

the so-called ‘exotic’ species (Enghoff 2011).

Figure 6.20: Left frontal of a red gurnard that was identified in the Thygeslund assemblage.

In addition, the remains of European anchovy were identified in the Havnø and Krabbesholm II assemblages. These are noteworthy since this species had been previously identified in an assemblage from Krabbesholm II by Enghoff (2011). The European anchovy has a similar present day distribution to the thinlip grey mullet and red gurnard. Furthermore, dragonet specimens were identified in the Havnø assemblage. Dragonet remains had only been identified from two other EBK assemblages, Asnæs Havnemark (Ritchie 2010) and Norsminde (Enghoff 1989).

6.5.4. The significance of the various groups of fish

6.5.4.1. Cartilaginous fishes (sharks and rays)

In the Havnø assemblage one dermal denticle/tooth belong to a very small specimen of the elasmobranchii sub order was identified. In addition, specimens deriving from spurdog were identified in the Havnø and Krabbesholm II material. While poor preservation has been cited as one reason for their low frequencies in EBK and TRB assemblages (Enghoff 2011), they have been recovered from a number of sites on Funen, Jutland and Zealand (Enghoff 2011; Noe-Nygaard 1995; Ritchie 2010). Spurdog is presently distributed in the northern North Sea, Skagerrak and Kattegat. During the summer it enters shallower waters, in particular the eelgrass zone where it preys on smaller species of fish often in shoals (Enghoff 2011).

6.5.4.2. Clupeidae

The remains of both European anchovy and Atlantic herring were identified in the four assemblages. Clupeidae specimens have only recently been identified from a number of sites in the Limfjord in east central Jutland and north Zealand (Enghoff 2011). Since their importance as a resource during the EBK and TRB is likely to have been downplayed, the results from this study demonstrate a methodological point that fine sieving should be routinely undertaken.

6.5.4.3. Salmonidae

Salmonidae specimens were represented in three of the four assemblages (Havnø, Krabbesholm II, and Thygeslund). Although they are present in numerous assemblages it has been suggested that they did not play a major role at any site (Enghoff 2011). The reason for their low frequencies is probably attributable to their remains that are poorly ossified, especially after the spawning period, and therefore susceptible to degradation. The relatively high Salmonidae specimens from the two kitchen middens in the Mariager Fjord is therefore very unusual and alters our perception of their exploitation during these periods.

6.5.4.4. European eel

European eel was identified in all four assemblages. They are routinely identified in Danish EBK and TRB assemblages, and were exploited throughout the country. Their presence is western Denmark is significantly higher than the eastern part of the country and has been interpreted as a representation of regional specialisation (Enghoff 2011) although differential recovery methods may have had a part to play (Ritchie submitted).

6.5.4.5. Gadidae

Gadidae were frequently encountered in the Havnø material (Figure 6.21), and were identified in the other three assemblages. Given their prevalence within Danish EBK and TRB assemblages their exploitation appears to have been of major significance (Enghoff 2011; Ritchie *et al*. 2013a). Atlantic cod can be caught from the shore to depths of ca. 600 m, whereas whiting, pollock and saithe are pelagic species occurring off the coast to ca. 200

m in depth (Muus and Dahlstrøm 1964). Given the broad range in their estimated TL within the four assemblages (1-50 cm) they were probably caught from both inshore and offshore waters possibly aided by dugout canoes and fishhooks.

Figure 6.21: Numerous Gadidae remains were identified in the Havnø assemblage and often represented single depositional events.

6.5.4.6. Flatfish

Flatfish represented by turbots (Scopthalmidae) or right-sided flounders (Pleuronectidae) were identified in the Havnø, Krabbesholm II, and Thygeslund assemblages. They are commonly identified in Danish EBK and TRB assemblages indicating that they were intensively exploited (Enghoff *et al*. 2007). Although it is often problematic to assign skeletal elements to the genus and species levels, there are a number of specimens that can be used (Enghoff 2011). Of the possible species, European flounder were the most frequently identified. In general, this species prefers brackish waters and are attracted to freshwater bodies, especially those that converge with saline waters. Thus, the numerous remains in the Havnø and Thygeslund assemblages attest to their habitat use and life histories. Often they are recovered from sites that are located on the coast near to the mouth of a freshwater source and/or inlet (Enghoff 2011).

6.5.4.7. Exotic species

While the majority of the identified species are presently distributed throughout Denmark, there are several that in the past have been termed exotic species (Enghoff 1991, 2011; Rosenlund 1986). These include smoothhound, common stingray, anchovy, European sea bass, black sea bream, swordfish, thin-lipped grey mullet as well as unspecified grey mullet (Enghoff 2011). Their presence in Danish Mesolithic and Neolithic assemblages (Table

6.12) have been interpreted as evidence for a warmer climate as well as higher salinities and water temperatures during the Atlantic and Sub Boreal chronozones since these halophile species have a more southerly distribution that is south of the English Channel (Degerbøl 1945; Enghoff 1995, 2011; Enghoff *et al*. 2007; Iversen 1973; Rosenlund 1986). In addition, the presence of wels catfish from a number of inland locations supports the notion for a warmer climate since they are now extinct in Denmark, possessing a more southerly and easterly distribution throughout Europe (Enghoff 2011).

Site	**'Exotic' species identified**	**Reference**
Bjørnsholm	Smoothhound, stingray, sea bass, black sea bream	Enghoff 1991, 2011; Rosenlund 1986
Bloksbjerg	Swordfish	Petersen 1996
Dragsholm	Sparidae	Ritchie 2010
Italiensvej	Swordfish	Enghoff 2011; Enghoff *et al*. 2007
Kalvø	Unspecified grey mullet	Enghoff 2011
Kainsbakke	Thinlip grey mullet	Richter 1986
Kolind	Thinlip grey mullet	Richter 1986
Krabbesholm II	Anchovy	Enghoff 2011; Enghoff *et al*. 2007
Lystrup Enge	Smoothhound	Enghoff 2011
Ordrup Næs	Thinlip grey mullet	Richter 1986
Svinninge Vejle	Stingray	Rosenlund 1986
Tastum Sø	Stingray	Rosenlund 1986
Vejleby	Thinlip grey mullet	Richter 1986
Yderhede	Seabass	Enghoff 1994, 2011

Table 6.12: The 'exotic' species from Atlantic and Sub Boreal period sites in Denmark.

In three of the four assemblages analysed, several of the exotic species were identified. In the Havnø material European anchovy, European sea bass and black sea bream were observed. The remains of blackspot sea bream, thinlip grey mullet and red gurnard represented additional exotic species. In the Krabbesholm II assemblage European anchovy

was identified, whereas in the Thygeslund material sea bass, thinlip grey mullet and red gurnard were present.

The presence of larger European eel specimens that were recovered from the EBK layers at Havnø also indicates that the climate was warmer during the Atlantic chronozone. However, the presence of several exotic species recovered from the Neolithic layers implies that at least for a part of this period the climate remained the same. This fact is supported by the presence of mullet at the Kalvø kitchen midden that is dated to the SGC (Enghoff 2011).

6.5.4.8. Freshwater taxa

Rarely are freshwater taxa identified in assemblages deriving from coastal sites, and only a small number of species have been recognized: pike, roach, rudd, bream, tench, perch and pikeperch. Naturally they are in abundance at inland locations from this period, for instance the complex of sites in the Åmose (Enghoff 1994, 1994-1995, 1995; Noe-Nygaard 1995). Bjørnsholm, Egsminde and Ertebølle in the Limfjord as well as Mejlgård and Østenkær are the only coastal sites where freshwater taxa have been observed in Jutland. In addition, there are a number of sites in the Nivå and Vedbæk Fjords on Zealand (Enghoff 2011). Eleven specimens deriving from freshwater taxa were identified in the assemblage from Dragsholm (Ritchie 2010). The presence of Esocidae, Percidae and Cyprinidae in the Dragsholm material was interpreted as either the lack of a large water body in the immediate vicinity of the site or that they were not intensively fished (Ritchie 2010).

In total 135 specimens belonging to freshwater taxa were identified in the Havnø assemblage, including common bream, pike, roach, rudd, tench as well as indeterminate cyprinid. A number of the above are able to tolerate brackish waters. At least 18 individuals are represented, and the remains derived from virtually all parts of the skeleton: the majority (65.2%) derived from the cranial and other elements, while the remainder (34.8%) are from vertebrae (Table 6.13). Only six showed traces of having been burnt, and there were no other pre-depositional processes. Therefore it seems likely that they were caught and processed elsewhere. If they had been cured before transportation to the island, traces

of either drying, salting or smoking are unlikely to have survived.

Taxon/skeletal element	Pike	Cyprinidae	Bream	Bream/roach	Bream/rudd	Roach	Roach/perch	Tench	Perciformes	Perch	Totals
Ante abdominal vertebra	8					1		1		2	**12**
Basioccipital	1										**1**
Caudal vertebra	2	4					5		1		**12**
Ceratohyal	1										**1**
Cranial element		6									**6**
Dentary	1										**1**
Fin ray		1									**1**
First vertebra	3	1									**4**
Gill rakers									24		**24**
Hyomandibular										3	**3**
Infrapharyngeal		1								1	**2**
Opercular	1	1				1		1		1	**5**
Palatine	4										**4**
Pharyngeal		3	2	1	1	6					**13**
Pharyngeal tooth		5				10					**15**
Post abdominal vertebra	8					2	1				**11**
Posttemporal		1									**1**
Quadrate		3									**3**
Tooth	8										**8**
Unknown		1									**1**
Unknown vertebra	1					1	2		2		**6**
Vomer										1	**1**
Totals	**38**	**27**	**2**	**1**	**1**	**21**	**8**	**2**	**27**	**8**	**135**
MNI	**3**	**2**	**2**	**1**	**1**	**4**	**1**	**1**	**1**	**2**	**18**

Table 6.13: Represented skeletal elements of the various freshwater taxa found in the material from Havnø.

Their presence is intriguing given the situation of the kitchen midden on the offshore island. Although the island is unlikely to have held any bodies of freshwater, a number of the species are able to tolerate brackish water and could have resided in the fjord where

they were caught, perhaps further upstream and not immediately off the island. The identified species able to tolerate brackish water included pike, bream, roach and rudd. However if they had been caught further upstream in the fjord it must have had a lower salinity at the time of material deposition. Since they have been recovered from both EBK and TRB layers a gradual reduction in the salinity is unlikely to have taken place in the fjord. What we are witnessing is probably occasional fishing in the hinterland and transportation to the island, a view supported by the stable carbon isotope value of a roach and the presence of thousands of oyster shells – a species unable to tolerate waters with a salinity <23‰ (Younge 1960).

Selected killing of pike during the spring has been demonstrated from several inland locations during the Danish Mesolithic (Noe-Nygaard 1983). Conceivably this could explain the presence of freshwater species in the Havnø assemblage. The smaller individuals of pike allude to summer exploitation. This suggests a degree of contact with the hinterland, a proposition supported by other faunal remains (Gron 2013a). Despite the ongoing analysis, when the beads from the kitchen midden have been identified, if to a freshwater mollusc, this would reinforce the notion for coastal-hinterland mobility or trade perhaps with another band of peoples.

The presence of freshwater taxa in the Havnø material is similar to both the Ertebølle and Mejlgård kitchen middens whereby European eel dominated the assemblage although freshwater fish were identified in abundance (Enghoff 1986, 2011). In the Krabbesholm II material, Cyprinidae, Percidae and European perch were identified. A total of 21 specimens were identified, and of these 20 derived from the EBK layers, whilst one from the TRB. In addition, in the Thygeslund material, one pike, 18 Cyprinidae specimens, one roach and one perch were identified.

6.5.4.9. Other taxa

Often EBK and TRB assemblages are represented by one dominating species that is supplemented by numerous additional taxa in varying quantities. The overall impression is that these taxa represented secondary catches from stationary trapping along the coast

(Enghoff 2011). They also demonstrate that whilst fishing may have been consciously exploited, for instance eel, the local waters surround these sites were favourable and species rich. This was true for Havnø.

At least 14 additional species were identified in the material. Their habitat use and life histories were equally as varied (anadromous, brackish/marine, freshwater/brackish, freshwater/brackish/marine and marine). However the three-spined stickleback and greater weever are two species that are more frequently encountered. In the Havnø assemblage both the three-spined stickleback (NISP = 42) and greater weever (NISP = 4) were identified, and in a previous study they constituted 19.0% of a column sample (Robson *et al*. 2013), represented by 54 three-spined stickleback remains and four greater weever specimens. Similarly the remains of three-spined stickleback were identified in the Krabbesholm II (NISP = 25), Norsminde (NISP = 1) and Thygeslund (NISP = 129) assemblages, and 124 greater weever specimens were observed in the Thygeslund material.

There are a number of sites in the Limfjord where the remains of three-spined stickleback have been recovered in considerable quantities. In the Bjørnsholm assemblage they constituted 7.0% of NISP (Enghoff 1991), while at Ertebølle they represented 50.0% of a column sample (Enghoff 1986). They occur in large shoals along the seacoast in the summer and can be easily caught in abundance.

Noteworthy are the relative frequencies of greater weever remains in the Thygeslund material. In comparison with other EBK assemblages, there is only one other site near to the small town of Trustrup on central Djursland where more greater weever remains have been identified (Andersen personal communication 2015), and their presence in all four assemblages supports the notion for passive fishery that was directed towards European eel (Havnø, Krabbesholm II and Thygeslund) and flatfish (Norsminde).

6.5.5. Fishing methods

Given the richness of material culture surrounding fishing during the Danish EBK and TRB, there are a number of methods that could have been employed (Appendix 5).

Distinction is made between active and passive fishing related implements in Appendix 5, however fishing related implements recovered from Havnø will be outlined briefly. During the excavations numerous bone awls and points were found. Made from the manufacture of bird and mammal remains they may have been used to cut up fish (Andersen personal communication 2009) or probably served as the central point to a fishing leister (Figure 6.22). In addition a total of four fish hooks (Figure 6.23) were recovered from the EBK layers and indicate line fishing in the waters surrounding the island, perhaps for larger specimens of European eel.

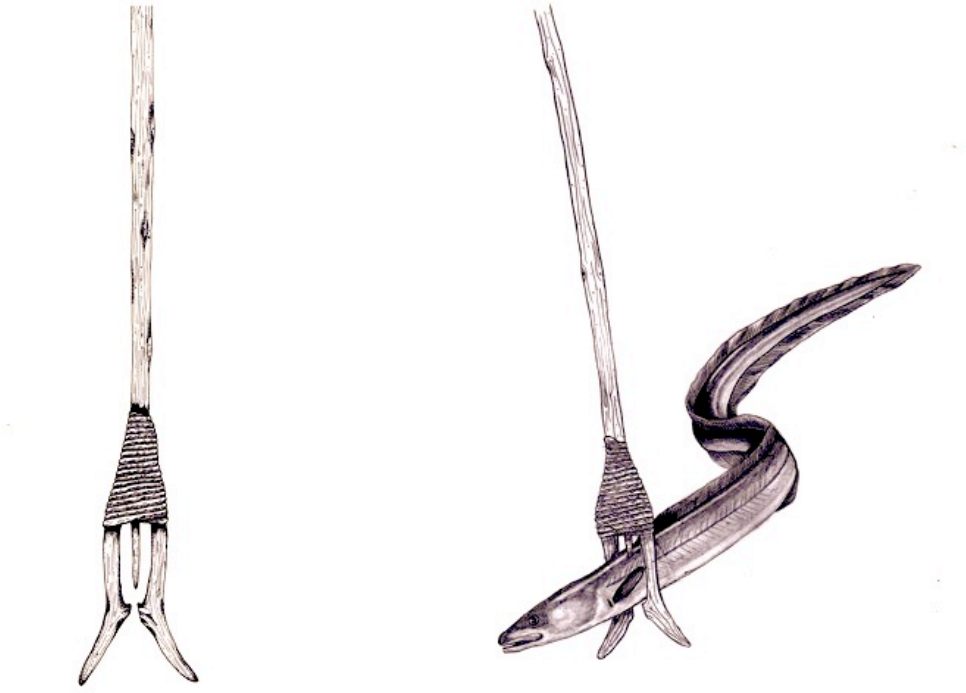


Figure 6.22: Reconstruction of the eel leister from Lolland-Falster (http://www.pasthorizonspr.com/index.php/archives/04/2015/ancient-fishing-leister-found-together-with-its-spearing-point-accessed 12/05/2015).

It must be borne in mind that fishing during the cooler seasons of the year would have been problematic due to freezing and poor weather (Pedersen 2013), therefore an active fishery is likely to have been undertaken during this period. However, during the warmer seasons of the year passive fishing permanent structures or traps in the shallow waters near to the

shore of the Havnø island were probably in place.

Figure 6.23: One of the four fishhooks in situ (scale 2 cm).

The species spectrum mainly comprised of diadromous and euryhaline fish and to a lesser extent freshwater and marine taxa. The dominance of European eel in the assemblage indicates that a conscious fishery of this species was undertaken, while the majority of the other taxa probably represent secondary catches. The tiny and small (0 to 30 cm in TL) individual specimens represented indicate residence in the brackish coastal waters of the fjord. Noteworthy are the freshwater taxa that were probably transported to the smaller barrier island.

6.5.6. Fishing for eel

Danish historical records (Drechsel 1890) state that numerous methods were utilised to exploit European eel, including traps (September to November), nets and fishhooks (June to September) and leisters (November to April). Taking the location of the kitchen midden into consideration that is consistent with the fishing site location model (Fischer 1993), the most efficient way of European eel fishing would have been by positioning permanent structures into the fjord. However in light of stable carbon and nitrogen isotope data from eel bone collagen (Robson *et al*. 2012) there are a number of possible explanations for European eel fishing and the population that was exploited: (1) The European eel represented in the assemblage derived from populations residing in marine dominated waters and could have been caught throughout the course of the year by hooks, nets, spears and traps (Drechsel 1890; Jensen and Olsen 1989; Muus and Dahlstrom 1964; Poulsen

1979). (2) As there would have been open access to the Kattegat proper there is no restriction in their movement and could have conceivably derived from freshwater. The protein turnover rate of wild fish is still unknown. (3) The notion that they were caught on their autumnal migration still stands if the population had moved from a more southerly location. As the species does not consume during its migration because it enters a semi-state of hibernation (Tesch 2003) they could have been caught by a non-baited method.

6.5.7. Use of fish

It is without a doubt that the exploited fish were primarily for human consumption, but the resource may have been used for other purposes. The spurdog could have been cured and stored for later consumption as its liver contains copious train oils. Its fins with their dermal denticles may have been used to polish wood (Brøndegaard 1985; Otterstrøm 1917), whereas their dorsal spines have been identified as tools (Noe-Nygaard 1971; Ritchie *et al*. 2013a). Three-spined stickleback equally may have provided train oils. European flounder similarly have dermal denticles that could have used (Enghoff 2011). In the Havnø assemblage 39 dermal denticles were identified. It is possible that the skin of shark, European eel and European flounder could have been used to manufacture clothing (Enghoff 2011).

6.5.8. Season of capture

In the past seasonal interpretations from the analysis of fish remains are, in general, restricted to the presence or absence of species or the inspection of their otoliths. Garfish, Atlantic horse mackerel and Atlantic mackerel have often been termed seasonal fishes since they only occur in Danish waters during the warmer periods of the year (Enghoff 2011). Although their remains are poorly ossified and therefore their representation is likely to have been biased, they have been recovered from nearly all of the regions throughout the country (Enghoff 2011; Ritchie 2010). On the other hand oxygen stable isotope values ($\delta^{18}O$) of Atlantic cod otoliths have recently demonstrated the seasonal water temperatures and therefore the season of capture for a number of archaeological sites in the region (Hufthammer *et al*. 2010; Ritchie *et al*. 2013b).

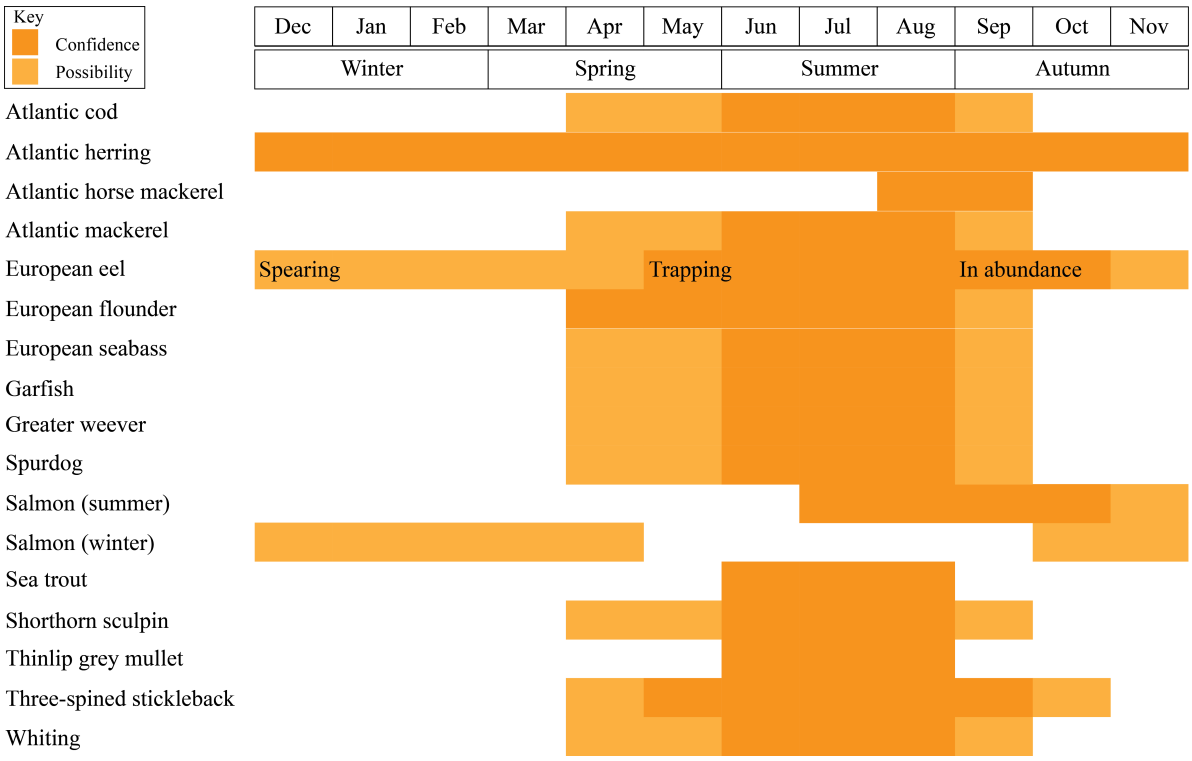


Figure 6.24: Seasonal indicators showing firstly that fishing could have been undertaken throughout the course of the year although was mainly a summer activity.

While interpretations are often based on the habitat use and life histories of the species concerned, it must be borne in mind that seasonal selection is not that straightforward, and is based upon a number of intricate factors (Milner 2002b, 2005). Nonetheless Figure 6.24 provides a summary of the seasonal indicators for Havnø. In general fishing was mainly a summer activity although was probably undertaken throughout the course of the year. The small specimens of Clupeidae, Atlantic herring and Gadidae individuals and the presence of spurdog, garfish, Atlantic mackerel and European flounder attest to this although are by no means conclusive.

Given the complex behavioural ecologies surrounding modern eel populations (Harrod *et al*. 2005) simply suggesting an eel fishery in the autumnal months is meaningless. The modern European eel population exhibits considerable ecological plasticity and it is suggested that a year-round operation was more than likely during the EBK and TRB – a practice supported by historical data on eel fishing throughout Denmark (Drechsel 1890).

In the Havnø, Krabbesholm II and Thygeslund assemblages both garfish and Atlantic mackerel remains were identified. Since modern populations enter Danish waters during the warmer months of the year, based on the assumption that their habitat use and life histories have not markedly altered they could have been caught from late spring to early autumn.

A number of diadromous taxa were represented in the four assemblages. These included Atlantic herring, Salmonidae, European eel and three-spined stickleback; the European eel has been discussed above. In a similar fashion, based on their habitat use and migratory patterns they are likely to have been caught from the late summer to the autumn although they could have been taken at different times of the year (Muus and Dahlstrøm 1964) if a passive fishery had been in place.

Gadidae remains in an assemblage have received more attention for assessing the season of death. Based on their habitat use, larger Gadidae are likely to have been caught during the cooler seasons of the year, whereas smaller individuals during the warmer seasons. It is during the summer months when smaller specimens remain close to the shore whilst larger and older Gadidae search for cooler temperatures in deeper waters. The recent application of stable isotope analysis is in agreement with the above and has been successfully applied to two EBK and TRB sites in the Denmark, the coastal settlement site at Asnæs Havnemark and the kitchen midden at Fårevejle (Ritchie *et al*. 2013b). The $\delta^{18}O$ values indicated that the Atlantic cod recovered from Asnæs Havnemark had been taken from the late winter until late summer, whereas those from Fårevejle had been caught during the coolest period of the year (Ritchie *et al*. 2013b). Gadidae remains deriving from smaller individuals were identified in the four assemblages.

6.5.9. Comparison with other assemblages

6.5.9.1. Introduction

Nearly 300,000 fish remains from over 80 Danish Mesolithic and Neolithic sites have been identified (Appendix 5). In general coastal fishing during the EBK and TRB was directed towards the European eel, Gadidae, in particular Atlantic cod, and Pleuronectidae. These

taxa were supplemented by a species rich secondary catch (Enghoff 1994, 2011; Ritchie 2010). Smaller species of fish are very well represented, and the differences in the relative frequencies of both the dominant taxa and the by-catches probably reflects the most readily available and easily procured species near to the site of deposition (Enghoff *et al*. 2007).

Given the comprehensive and impressive dataset to work with it is possible to assess regional variation. In light of the four assemblages here, three fjord systems on the Jutland peninsula (Mariager, Limfjord and Norsminde Fjord) will be discussed before a brief overview of the fisheries on the islands of Funen and Zealand.

6.5.9.2. Mariager Fjord

In the Mariager Fjord at least four kitchen middens have been intensively excavated (Åmølle, Havnø, Thygeslund and Visborg) producing variable quantities of fish remains. Two of those assemblages have been analysed in this study, Havnø and Thygeslund.

During the investigations by *The Second Kitchen Midden Commission*, three of the aforementioned sites were excavated: Åmølle, Havnø, and Visborg. In the Åmølle material a few vertebrae deriving from small fish were present although could not be identified (Madsen *et al*. 1900), whereas the Visborg kitchen midden was not published. On the other hand seven fish bones were recovered from Havnø and were represented by European eel (NISP = 5) and Pleuronectidae (NISP = 2) (Winge 1900).

Prior to this project the number of identified specimens in the Havnø assemblages totalled 643 (Ritchie 2010; Robson 2011; Winge 1900). Consequently statements regarding the nature of fishing undertaken by the inhabitants were by no means conclusive, and it appeared that fish remains were uncommon throughout the kitchen midden (Ritchie 2010). However the application of meticulous excavation techniques during the remainder of the investigations has resulted in the identification of 2,675 specimens, an essential contribution to the otherwise small assemblage. When the four assemblages are combined, at least 35 species from 27 families were represented in the material. The assemblage currently stands as the most diverse dating to the Danish EBK and TRB. European eel

dominated all four assemblages and was supplemented by a diverse secondary catch.

In comparison, a relatively small assemblage was analysed from a recently excavated kitchen midden, Thygeslund that is located < 5 km to the west of Havnø. At least 16 species from 16 families were identified in the assemblage. Unlike Havnø three-spined stickleback dominated the assemblage and was followed by European eel and greater weever. The fishing was probably chiefly directed towards the European eel, and the three-spined stickleback and greater weever represented secondary catches.

The kitchen midden at Visborg is located < 5 km to the north west of Havnø and was excavated from 1995 to 2002. A total of 227 fish remains were identified and of these only 186 fish remains could be identified to the species or family level. At least seven families were represented, and of these 6 species were identified (Enghoff 2011). Compared with both Havnø and Thygeslund the assemblage is significantly smaller and is probably attributable to the poor conditions of preservation. Only a very thin shell layer was preserved at Visborg due to compression by heavy agricultural machinery (Enghoff 2011) and deep ploughing for cultivation.

In general, fishing in the Mariager Fjord was directed towards the exploitation of the European eel, which was supplemented by a diverse secondary catch. In addition, all three assemblages demonstrated that fishing continued across the Mesolithic-Neolithic transition.

6.5.9.3. Limfjord

The Limfjord has probably received the most attention in terms of kitchen midden research in the country and has been intermittently investigated since the 1840s (Andersen 2000a). Consequently there are numerous kitchen middens and shell-bearing sites scattered along the former coastlines. At least nine sites have been intensively excavated, and of these seven yielded fish remains (Aggersund, Åle, Bjørnsholm, Egsminde, Ertebølle, Krabbesholm II and Signalbakken) (Enghoff 2011). The kitchen middens at Bjørnsholm, Ertebølle and Krabbesholm II will be discussed.

The assemblages from all three kitchen middens have been interpreted as migratory European eel fisheries that were occupied during the late summer to autumn (Enghoff 1986, 1991, 2011). The size frequency diagrams for a number of taxa support this interpretation (Enghoff 1994). In the Bjørnsholm material European eel represented 56.3% and was supplemented by Gadidae. In comparison perch dominated, while European eel constituted 17.5% of the overall Ertebølle assemblage. In the Krabbesholm II assemblage the species constituted 41.8% of the material that was analysed previously (Enghoff 2011) and 71.6% of the fish remains that were analysed in this study. In both studies three-spined stickleback were frequently identified and have been interpreted as secondary catches.

In the Limfjord fishing for the European eel is likely to have been of primary importance, as it is known that they congregate *en masse* and can be easily exploited (Enghoff 2011). However the carbon and nitrogen stable isotope analysis of eel bone collagen from the Krabbesholm II kitchen midden has demonstrated that they are likely to have resided in marine dominated waters where they were subsequently caught. As there would have been open access to the North Sea there would have been no restriction in their movement.

Assessing the degree of temporal change is problematic in the Limfjord too. At the Bjørnsholm kitchen midden European eel exploitation continued across the EBK-TRB transition, whereas the Ertebølle kitchen midden dates solely to the late Mesolithic. At the Krabbesholm II kitchen midden there is a general paucity of fish remains from the TRB layers despite the fact that only one EBK layer has been identified.

6.5.9.4. Norsminde Fjord

Similarly the Norsminde Fjord has been intensively excavated since 1945, and at least 15 sites have been subjected to investigations. A number of these have yielded fish remains in varying quantities (Flynderhage, Frederiks Odde, Kalvø, Norslund, and Norsminde), and only two kitchen middens (Kalvø and Norsminde) will be discussed given the relatively small assemblages for the other sites.

The Norsminde assemblage differed to those in the Mariager Fjord and Limfjord and was

dominated by Pleuronectidae that represented 51.6% of the NISP. In addition 427 remains could be identified to the European flounder. Gadidae followed this at 27.1% and European eel at 8.6%. The kitchen midden was probably occupied during the summer for European flounder exploitation since they congregate *en masse* prior to penetration into freshwater. The location would have been ideal for the exploitation of this species (Enghoff 1989).

Despite the fact that the kitchen midden has been totally excavated (Andersen 1989) all but one Gadidae vertebra were recovered from the EBK layers and kitchen midden at the site. Based on this site alone it is not possible to assess temporal change across the Mesolithic-Neolithic transition. However, the Kalvø kitchen midden that has been dated to the SGC demonstrated that fish continued to be exploited well into the Neolithic. The assemblage was dominated by Atlantic cod and Pleuronectidae representing 45.2% and 22.3% respectively (Enghoff 2011).

6.5.9.5. Funen and Zealand

In comparison with western Denmark, fishing in the eastern part of the country was, in general, directed towards the Gadidae, in particular Atlantic cod. Pleuronectidae and European eel followed these taxa. At least 38 other species were represented and contributed relatively minor amounts (Enghoff 2009, 2011; Ritchie 2010; Trolle-Lassen 2013), however discrepancies in mesh size between the east and west of the country may have had a part of play (Ritchie submitted). Freshwater taxa are less represented at coastal locations although are naturally in abundance at inland locations (Enghoff 1994, 1995; Noe-Nygaard 1995). The fisheries were probably in operation all year round as has been demonstrated by the size of their remains as well as the stable oxygen isotope values of Atlantic cod (Ritchie *et al*. 2013b). In addition, angling continued across the Mesolithic-Neolithic transition.

6.5.10. Temporal change

Given the abundance of well-analysed assemblages represented by both EBK and TRB habitation episodes it is possible to assess the degree of temporal change across the transition. Despite the relatively few fish remains from the TRB deposits from the kitchen

middens at Krabbesholm II, Norsminde and Visborg, the Bjørnsholm, Havnø, Magleholm and Thygeslund sites have EBK and TRB assemblages in varying quantities (Enghoff 2011; Robson *et al*. 2013).

At Bjørnsholm fishing continued in a rather unaltered manner given the similar spectrum of species and relative abundance (Enghoff 1991, 2011). At Krabbesholm II the exploitation of the European eel fishing continued, whereas at Magleholm a similar pattern to that of Bjørnsholm was observed with the assemblage being chiefly composed of Gadidae and spurdog (Enghoff 2011). In addition the exploitation of Atlantic cod and Pleuronectidae supplemented by greater weever and eelpout continued from the EBK to the TRB at Visborg (Enghoff 2011). At the present it would be unwise to assess the degree of temporal change at Thygeslund given the on-going course of AMS radiocarbon dating, and post excavation analysis.

Unlike the Havnø assemblage there is a general paucity of fish remains deriving from Neolithic contexts at other sites, for example Norsminde. While it was original proposed that fishing played a minor role during this period (Enghoff 1989), taphonomic factors are the most likely explanation. On the whole, the TRB layers at a given site are located higher up in the sequence and therefore are more susceptible to post depositional alteration. In support of the above the faunal remains were, in general, highly fragmented in the Norsminde assemblage. It is possible that the low identifiability rate is probably due to colluvium since deposition (Gron personal communication 2015). However, the kitchen midden at Kalvø has demonstrated that fishing (Enghoff 2011) as well as oyster exploitation continued into the SGC (Andersen 1983). In general the assemblage was dominated by Gadidae, in particular Atlantic cod and has shown that these specimens were larger than those from both the EBK and TRB. Perhaps an increase in the local biotope between the TRB and SGC took place in the fjord.

6.6. Conclusions

Although stable carbon and nitrogen isotope analysis of bone collagen has frequently demonstrated a reduced reliance on aquatic resources (Chapter 3), the analysis of ceramic

shards has demonstrated the continued processing of fish (Chapter 5). In addition, there are numerous sites, in particular kitchen middens that continued well into the Neolithic (Andersen 2000a, 2007, 2008a; Milner *et al*. 2004, 2006). Furthermore, extensive fish procurement implements dated to the TRB have been recovered from numerous locations along the Danish coastline (Pedersen 1995, 2013). The results from this study are consistent with the exploitation of aquatic resources during the Neolithic when domesticated fauna and flora became more readily available.

To assess whether a change in the fishery across the Mesolithic-Neolithic transition took place at Havnø over 10,000 fish remains were analysed. A total of six complete column samples excavated from several locations throughout the kitchen midden, hand collected material as well as fish remains recovered during the post excavation processing of samples were analysed.

Despite the relatively low NISP when compared with previous studies on fish remains recovered from Danish kitchen middens, at least 33 species of fish deriving from 27 families were identified in the material. The species spectrum is the most diverse dating to EBK and TRB in Denmark. The primary focus was fishing for the European eel, whereas the numerous other species represented by relatively few remains (NISP = <10) probably reflect secondary catches. Despite this, Clupeidae, Gadidae and flatfish (Scopthalmidae/Pleuronectidae) comprised a reasonable proportion of the assemblage. The majority of these taxa are able to tolerate brackish waters. Very few specimens derived from chiefly freshwater or marine taxa. In general the assemblage probably reflects the brackish conditions of the fjord's confluence with the saline waters of the Kattegat (Robson 2011). However the waters immediate surrounding the island were probably more saline – a fact supported by the carbon and nitrogen isotope analysis of eel bone collagen from the kitchen midden (Robson *et al*. 2012).

The majority of the fish remains were derived from European eel. The second most frequent taxon was the Atlantic cod followed by Pleuronectidae, Gadidae, Clupeidae and European flounder. Thirty additional species were also identified. Owing to the meticulous

excavation of six columns that were intensively screened (2.5, 1.0 and 0.5 mm mesh size), as well as the extraction of numerous samples from throughout the kitchen midden, regardless of identifiability, the majority (97.6%) of the fish remains were <1 cm in size. The previous view that fish remains were uncommon throughout the kitchen midden does not stand (Ritchie 2010). However, since not all of the matrices were dry-screened, numerous smaller specimens are likely to have been lost during the excavations (Ritchie 2010).

In general, the fish remains did not have a uniform horizontal and vertical distribution. It is likely that the differences in the frequency of identified fish remains are not a reflection of the recovery methods since four of the columns were excavated by the author who also oversaw the excavations of the other two undertaken by the same volunteer. Consequently the material is probably a reflection of the thickness of the midden sequence and differential preservation across the site. The thickest shell deposits were encountered in the midden proper and it is from this area where the most fish remains were recovered and identified (columns ACAA and YAA). This was followed by columns AFAA and AFBE that were excavated to the west of the 1894 trench. They were followed by column ACDD that was excavated from the most southerly location in the kitchen midden. Two meters to the north, columns AFCF and AFDC were excavated, which were adjacent to one another. Since this area had been heavily disturbed it is not surprising that the least specimens were recovered.

For inter-site comparison three assemblages deriving from the kitchen middens at Krabbesholm II, Norsminde and Thyglesund were analysed. On the whole the fisheries undertaken at these localities were broadly similar to one carried out at Havnø. At Krabbesholm II and Norsminde the assemblages were predominantly composed of the European eel that were followed by Atlantic herring and Gadidae respectively. While the three-spined stickleback dominated the Thygeslund assemblage, it probably represented a secondary catch.

For additional comparison contemporaneous archaeological sites in Jutland were examined

including Bjørnsholm. At this kitchen midden a total of 11,742 fish remains were identified (Enghoff 1991), and, of these, 252 were dated to the TRB. Although the Havnø assemblage is considerably smaller in terms of NISP: NISP = 330 (Ritchie 2010), NISP = 7 (Winge 1900), NISP = 306 (Robson *et al*. 2013), and 2,675 (this study) – at least 225 fish remains derived from the Neolithic. When the fish remains that could not be further identified to the genus and species levels are included, the Neolithic assemblage from Havnø is the largest to date (n = 737).

In conclusion, the Neolithic assemblage is significant as it demonstrates that European eel exploitation continued across the Mesolithic-Neolithic in the Mariager Fjord. In addition, Atlantic herring, Salmonidae, garfish, three-spined stickleback, Cyprinidae, roach, Gadidae, sea bass, sea bream, Atlantic mackerel, eel pout, red gurnard, perches and flatfish were also caught. A similar fishery has also been identified in the Limfjord represented by Bjørnsholm and Krabbesholm II (Enghoff 1991, 2011). However, it is possible that spurdog and Atlantic mackerel are probably poorly represented in the TRB layers at the site. Of the six columns, only six specimens were recovered from the one TRB layer of column AFDC and there was an absence of their remains from throughout the other columns.

7. Discussion and conclusion

7.1. Introduction

This chapter summarises the key points from the stable isotope, incremental growth line, organic residue and fish remains analyses undertaken on material derived from Havnø. When these are combined it is then possible to address the aim of the thesis: to evaluate whether a change in diet, consumption practices and subsistence occurred across the Mesolithic-Neolithic transition at the Havnø kitchen midden. The chapter will conclude with suggestions for possible future analyses that could be undertaken from these class of archaeological site.

7.2. Turning their backs on the sea

Despite the numerous studies that have been undertaken to reconstruct the diet of the humans dating to the late Mesolithic and early Neolithic periods in Denmark, Chapters 1 and 3 highlighted that there are numerous issues associated with the interpretation of the stable isotope data of human bone collagen. For instance the late Mesolithic sample set is primarily based on human remains recovered from coastal localities. In general, the sampled early Neolithic humans are derived from inland locations. Since these data are always plotted alongside one another it is not surprising that every study has argued for a dietary shift concurrent with the arrival of domesticated fauna and flora. In addition, Chapter 3 highlighted that there are, in general, a dearth of data deriving from human remains recovered from kitchen middens. Prior to this study the current dataset on human remains derived from kitchen middens totalled 11.

In this study stable isotope data were obtained from 23 human remains derived from two kitchen middens, Havnø and Holmegård. At Havnø the 23 skeletal elements are thought to belong to at least 5 different individuals: adult (2) dating to the EBK, juvenile (2) dating to the TRB, adult (1) and juvenile (1) dating to the PWC and SGC cultures, as well as one undated individual (adult 3). The results show a clear dietary change across the Mesolithic-Neolithic transition. However, the one adult sampled from Holmegård, which is dated to

the EBK, had a diet that was consistent with the long-term consumption of marine derived protein.

Overall these data were consistent with the current sample set. However, when these data were plotted alongside other human remains sampled from contemporaneous kitchen midden and their associated AMS radiocarbon dates the dietary change was not as dramatic or sudden as inferred by some scholars. On the whole the consumption of marine derived protein continued for several centuries at the beginning of the TRB. At Havnø it would appear that the Neolithic individuals substituted high trophic level marine resources with terrestrial resources that were combined with a mixture of aquatic resources, and not the substitution of high trophic level marine resources with domesticated fauna and flora (Tauber 1981).

7.3. Plugging the gap and the oyster decline

Despite the preponderance of oysters that were deposited at the Danish kitchen middens, in general, interpretation has largely focussed on their position within the overall economy and ranking of species (Rowley-Conwy 1984). While comprehensive research (Milner 2001a, 2002a, 2005, 2013) has largely been in agreement with Rowley-Conwy (1984) the data obtained from Havnø were significantly different to those observed elsewhere. Chapter 4 demonstrated that at Havnø the harvesting of oysters during the EBK appeared to be focussed towards the spring *and* summer. The hypothesis that a change in the seasonal exploitation of the oyster across the transition to the Neolithic at the kitchen midden was not proven as there was an identical pattern of collection events within the TRB contexts. However, there was evidence for overexploitation or at the very least intensification of the gathering of oysters, as evidenced from a diminution in age and size over time.

When these data were compared with 15 contemporaneous archaeological sites in Denmark the situation was far from straightforward. On the whole the data demonstrated that the seasonality of oyster harvesting varied from site to site, and that all sites differed. While there was a dominance of spring collection during both the EBK and TRB cultures there were also other patterns that demonstrated different collection events that may reflect

environmental change or human preferences.

7.4. Continuity in culinary practices

Despite the comprehensive analyses undertaken on EBK and TRB ceramic vessels from Denmark the application of ORA to ceramic sherds recovered from the Danish kitchen middens is restricted to two studies. Overall, the GC, GC-MS and GC-C-IRMS undertaken in this study (Chapter 5) have confirmed the presence of lipids in association with EBK and TRB vessels recovered from the Havnø kitchen midden. In addition, molecular signals were preserved that could be identified by GC-MS. The analysis has shown that a variety of biomarkers and products were present in the ceramic vessels.

The single compound isotope data demonstrated that there was evidence for temporal change across the Mesolithic-Neolithic at Havnø. In sum, the EBK ceramics were used to process a combination of resources including aquatics and ruminants, whereas the TRB funnel beakers were primarily used to process or store ruminant foodstuffs. In one of the sherds dairy was processed. Despite the proximity to the coast and the preponderance of aquatic resources available, only one EBK vessel had been used for processing aquatic organisms.

Comparison with other contemporaneous Danish ceramic vessels recovered from both coastal and inland localities as well as the comprehensive analysis undertaken from material throughout southern Scandinavia has shown that Havnø differed to some degree from the norm (Craig *et al*. 2007, 2011; Heron *et al*. 2007, 2013). In general, the analyses have demonstrated the necessity for applying different analytical techniques to determine vessel use and culinary change at the Mesolithic-Neolithic transition. Via the powerful combination of the different methods available to us it is now possible to disaggregate economy and evaluate choices (Saul *et al*. 2014).

7.5. Touch not the fish

To date nearly 300,000 fish remains from over 80 Danish Mesolithic and Neolithic sites have been identified. Of these, the majority are derived from EBK contexts thus making it

difficult to assess the degree of temporal change. In this study over 14,000 fish remains were analysed and demonstrated that fishing continued across the Mesolithic-Neolithic at the Havnø kitchen midden. Chapter 6 showed that the European eel was preferentially exploited in the TRB although other species were also caught, including Atlantic herring, Salmonidae, garfish, three-spined stickleback, Cyprinidae, roach, Gadidae, sea bass, sea bream, Atlantic mackerel, eel pout, red gurnard, perches and flatfish.

For comparison, three smaller assemblages recovered from contemporaneous stratified kitchen middens were analysed: Krabbesholm II, Norsminde and Thygeslund. Equally these data demonstrated that European eel exploitation continued across the Mesolithic-Neolithic transition in the Mariager Fjord and Limfjord.

7.6 An overview of consumption at the Mesolithic Neolithic transition at Havnø

The data presented in this thesis are important because they demonstrate a degree of complexity when interpreting whether a change in the dietary and consumption practices took place across the Mesolithic-Neolithic transition. When the other sites as well as the regional context are taken into consideration certain patterns emerge: on the whole there was evidence for a change in diet and subsistence as evidenced by the suite of techniques presented in this thesis. However, in terms of what happened at Havnø, and some other sites, there is strong evidence for the continued exploitation of aquatic resources: it is possible to argue that the early Neolithic peoples did *not* turn their backs on the sea.

There is a fairly consistent pattern throughout Denmark from the stable isotopic data alone that peoples' diet changed from one consistent with the consumption of marine to one largely derived from terrestrial protein. However, the food remains themselves are quite the contradictory: oysters and fish are still being processed and consumed, and there was evidence for the cooking of aquatic resources as demonstrated by the residue analysis of ceramic vessels albeit on a much reduced scale.

Since carbon and nitrogen stable isotopes reflect the long-term dietary intake of the foods

consumed, to infer a blanket change across the Mesolithic-Neolithic transition is misleading. The other lines of evidence demonstrate that the situation is not straightforward. By the examination of a kitchen midden like Havnø using a suite of techniques it is possible to elucidate how some traditions continued such as the seasonal exploitation of oysters and fishing, albeit on a smaller scale, and the continued processing of aquatic resources as evidenced by the presence of biomarkers.

The differences observed between the sites were also interesting. For instance, the incremental growth line analysis demonstrated that spring was the primary season when oysters were harvested but there are numerous differences in terms of other seasons. Some sites appeared to show clear evidence over time for purely spring gathering. Other sites including Havnø showed a broader range of seasons of gathering. Interpreting this data is difficult: it is hard to say whether this is because of the availability of resources, or cultural practices, for example people only visiting the site in the spring. In addition, when the data is viewed spatially it can be seen that there are different collection events in different areas of the site. Examining the data at this scale provides an important insight into consumption practices and emphasizes that it should not be assumed that the whole of Denmark the same practice was undertaken over a long period of time.

In conclusion, this thesis emphasizes an important methodological point. Whilst a dietary change appeared to have occurred to some degree throughout the region it was more subtle and nuanced than it was often believed, and local variability should always be borne in mind.

Often the exact timing of the transition to agriculture is assumed although it will never be possible to determine absolutely where the first domesticated fauna and flora were killed or cultivated. What can be stated with certainty is that marine resource exploitation continued but there were differences, perhaps in terms of scale. It would appear that at Havnø a gradual decline in the long-term consumption of marine derived protein took place. These data are consistent with the suggestion by Price (1996) that agriculture became the primary subsistence economy from the middle to the late Neolithic.

7.7 Potential future research

Throughout the thesis several important methodological factors have been highlighted, such as the sampling from multiple localities within a site to examine intra-site variability as well as the employment of column sampling to assess temporal change. While this thesis employed a suite of techniques there are a number that were beyond the scope of the study but which could be usefully applied to further the understanding for a change in subsistence across the Mesolithic-Neolithic transition:

1. Peptide mass fingerprinting (ZooMS) of the bone material from the kitchen midden would potentially identify additional human remains as well as fauna that were unidentified during the osteological and zooarchaeological analyses. In addition, ZooMS and aDNA analyses would be usefully applied to distinguish between taxa that could not be identified to the lower family, genus or species levels, for instance the flatfish, and Salmonidae.
2. The analysis of dental calculus of human remains from kitchen middens and contemporaneous sites would potentially enhance our knowledge of the palaeodiet including animal muscle, bacteria, DNA, pollen, and starch grains (Warriner *et al*. 2014a, 2014b).
3. The organic residue and use-wear analyses of worked antler, bone and lithics could be usefully applied to identify resources that had been processed (Högberg *et al*. 2009).
4. Further analysis of contemporary faunal remains could be carried out to reconstruct the local baseline for the interpretation of the human stable isotope data. In doing so, intra-site and intra-regional variability can be taken into consideration.
5. Sulphur stable isotope analysis could be used as an additional dietary discriminator. However, the low success rate necessitates additional analyses of materials from archaeological sites in the region to explore its applicability.
6. Lipid residue analysis of human remains could be applied in the future to attain additional palaeodietary information of the consumer including discrimination between marine and terrestrial consumers as well as essential fatty acids (Colonese *et al*. 2015).

7. Furthermore, strontium and oxygen stable isotope analyses of human and mammalian teeth could be undertaken in the future in order to determine the place and season of birth that may demonstrate either importation or acculturation (Gron *et al*. 2015).
8. In order to obtain short-term episodic consumption practices of different ages in different individuals, incremental detine sampling of teeth could be undertaken (Montgomery *et al*. 2013).
9. As has been undertaken at other kitchen middens, for example Krabbesholm II and Norsminde (Laurie 2008) incremental growth line analysis of the common cockle would be a useful adjunct to the data presented in this thesis.
10. In addition, it would be useful to do a shoreline and shallow sea analysis to determine the relative importance of oysters and other mollusc species through time which could indicate changes in shore and shallow sea use through this midden (Laurie 2008).
11. Since kitchen middens offer the best opportunity for analysing the degree of Neolithisation by the earliest pastoralists of southern Scandinavia it would be interesting to thoroughly analyse additional ceramic vessels from these types of sites. In a similar manner to the stable isotope data of human bone collagen there is a dearth of EA-IRMS and GC-MS derived data from EBK vessels from inland localities as well as TRB ceramics from coastal sites. Furthermore, sampling of blubber lamps from Danish sites-but not restricted to would be of interest. In order to complement the macro- and micro-fossil, EA-IRMS, GC and GC-MS analyses of the ceramic sherds from Ronæs Skov, GC-C-IRMS should be carried out. While regional variation in the form of the EBK vessels has been identified (Andersen 2011b), the application of ORA to these specimens is perhaps another research question. Lastly, the analysis of ceramic vessels should combine the multiple methods available, for instance IRMS, GC, GC-MS, and GC-C-IRMS to ascertain a more holistic understanding of vessel use at the transition to agriculture.
12. In order to obtain additional seasonality information as well as palaeoenvironmental reconstruction it would be interesting to build on previous stable oxygen isotope

studies (Hufthammer *et al*. 2010; Ritchie *et al*. 2013b) through the analysis of Gadidae and Pleuronectidae otoliths from EBK and TRB assemblages.

13. Lastly, to discriminate between terrestrial and aquatic resource consumption, compound-specific amino acid carbon-isotope dietary proxies could be usefully applied (Webb *et al*. 2015).

7.8 Conclusion

This thesis marks the first large-scale application using a suite of techniques to materials derived from one kitchen midden. Through the combination of the four different datasets it has been possible to contribute to on-going debates concerning the speed and completeness for this fundamental economic and social change, characterised by the onset of the Neolithic. In general, the data are not always in agreement with previous research. Moreover, the results from this study demonstrated a degree of complexity regarding the extent of dietary change across the Mesolithic-Neolithic transition. In addition, the data highlight the importance for examining individual sites in detail. By comparison with materials derived from 32 additional and contemporaneous sites it is evident that there was variation on an intra- and inter-site scale as well as between different regions.

Due to the nature of the transition, for instance the lack of pre-Neolithic pottery in the British Isles (Cramp and Evershed 2014) as well as small faunal assemblages with taxa of marine origin (Serjeantson 2011), it is difficult to compare the unique data rich assemblages found throughout southern Scandinavia to different regions. Regardless, the following will provide a brief comparison with the British Isles in light of recent research (Cramp *et al*. 2014).

To date, the carbon and nitrogen stable isotope analyses undertaken on human bone collagen derived from the British Isles has consistently demonstrated that there was a marked change in diet at the onset of the Neolithic. Similarly, it has been argued that the late Mesolithic individuals had a diet associated with the long-term consumption of marine derived protein (Richards and Mellars 1998), whereas the early Neolithic peoples appeared to have consumed significant quantities of terrestrial derived protein (Richards *et al*. 2003b;

Richards and Hedges 1999; Schulting and Richards 2002). Interestingly, emergent data from the Channel Isles was largely in agreement with the data derived from more northerly localities (Schulting *et al*. 2010). Despite the inherent biases, sample size in particular, the data are, in general, largely in agreement with previous studies undertaken on human bone collagen recovered from southern Scandinavia including Denmark.

Since there was no existing tradition of ceramic manufacture before the Neolithic in the British Isles it is not possible to compare pottery use before and after the transition to the Neolithic. Despite this caveat, more than 400 sherds derived from 48 assemblages dating to the Neolithic have recently been reported by Cramp *et al*. (2014). In comparison with southern Scandinavia there was a near complete absence of aquatic biomarkers in the earliest Neolithic ceramics. However, some 80% of the lipid residues that were identified demonstrated that products of dairy origin had been processed or stored in the vessels. These data alongside other lines of evidence led Cramp *et al*. (2014) to conclude that 'marine products were of low importance during the Neolithic compared with those of terrestrial origin' (5).

In light of the above and the data presented in this thesis it would appear that the Neolithisation process did not occur instantaneously or contemporaneously throughout northern Europe. A more plausible scenario whereby regionally distinctive influences affected the evolution of consumption and culinary practices is envisaged at this critical moment in prehistory (Cramp *et al*. 2014).